# NAVAL POSTGRADUATE SCHOOL
## Monterey, California



# THESIS

**CONNECTIVITY FOR UNDERWAY COAST GUARD PATROL BOATS**

by

Gregory C. Busch

June, 1997

Thesis Advisor: Suresh Sridhar
Second Reader: Rex Buddenberg

**Approved for public release; distribution is unlimited.**

# REPORT DOCUMENTATION PAGE

*Form Approved OMB No. 0704-0188*



| 1. AGENCY USE ONLY *(Leave blank)* | 2. REPORT DATE | 3. REPORT TYPE AND DATES COVERED |
|---|---|---|
| | June 1997 | Master's Thesis |

4. TITLE AND SUBTITLE
CONNECTIVITY FOR UNDERWAY COAST GUARD PATROL BOATS

5. FUNDING NUMBERS

6. AUTHOR(S)
Busch, Gregory C.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense, Department of Transportation or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. **ABSTRACT** ***(maximum 200 words)***

This thesis examines the US Coast Guard patrol boat's ability to effectively exchange operational data while underway. The patrol boat is currently unable to obtain tactical law enforcement information from the central Law Enforcement Information System II (LEIS II) database while on patrol. LEIS II provides access to law enforcement information from Coast Guard, FBI, and state and local law enforcement agencies. Availability of this information will alert the boarding team of potentially dangerous situations and heighten their awareness during the boarding, allowing for a safer boarding.

This thesis evaluates the current state of the patrol boat's communication system and recommends a solution to its current needs. Current and proposed satellite communication systems are evaluated using the Analytic Hierarchy Process (AHP). Pairwise comparisons are made of multiple decision criteria and the alternatives to obtain a recommended solution.

The conclusion of this study is that the patrol boat's future requirements will far exceed the bandwidth available from current satellite systems. Broadband mobile communication systems such as Teledesic and Spaceway are currently under development and show promise. Until broadband service is available, Iridium should be adopted as the solution to the patrol boat's current needs.

14. SUBJECT TERMS
LEIS II, Coast Guard, Patrol Boat, Iridium, Globalstar, Odyssey, AMSC, DirecPC, Spaceway

15. NUMBER OF PAGES
111

16. PRICE CODE

| 17. SECURITY CLASSIFICATION OF REPORT | 18. SECURITY CLASSIFICATION OF THIS PAGE | 19. SECURITY CLASSIFI- CATION OF ABSTRACT | 20. LIMITATION OF ABSTRACT |
|---|---|---|---|
| Unclassified | Unclassified | Unclassified | UL |

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by existing ANSI Std. 239 18

**Approved for public release; distribution is unlimited**

# CONNECTIVITY FOR UNDERWAY COAST GUARD PATROL BOATS

Gregory C. Busch
Lieutenant Commander, United States Coast Guard
B.S., United States Coast Guard Academy, 1986

Submitted in partial fulfillment of the
requirements for the degree of

**MASTER OF SCIENCE
IN
INFORMATION TECHNOLOGY MANAGEMENT**

from the

**NAVAL POSTGRADUATE SCHOOL
June 1997**

Author: ______________________
Gregory C. Busch

Approved by: ______________________
Suresh Sridhar, Thesis Advisor

______________________
Rex Buddenberg, Second Reader

______________________
Reuben T. Harris, Chairman
Department of Systems Management

## ABSTRACT

This thesis examines the US Coast Guard patrol boat's ability to effectively exchange operational data while underway. The patrol boat is currently unable to obtain tactical law enforcement information from the central Law Enforcement Information System II (LEIS II) database while on patrol. LEIS II provides access to law enforcement information from Coast Guard, FBI, and state and local law enforcement agencies. Availability of this information will alert the boarding team of potentially dangerous situations and heighten their awareness during the boarding, allowing for a safer boarding.

This thesis evaluates the current state of the patrol boat's communication system and recommends a solution to its current needs. Current and proposed satellite communication systems are evaluated using the Analytic Hierarchy Process (AHP). Pairwise comparisons are made of multiple decision criteria and the alternatives to obtain a recommended solution.

The conclusion of this study is that the patrol boat's future requirements will far exceed the bandwidth available from current satellite systems. Broadband mobile communication systems such as Teledesic and Spaceway are currently under development and show promise. Until broadband service is available, Iridium should be adopted as the solution to the patrol boat's current needs.

## TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

## LIST OF SYMBOLS, ACRONYMS AND/OR ABBREVIATIONS

| | |
|---|---|
| ACPMS | Aviation Computerized Preventive Maintenance System |
| AHP | Analytic Hierarchy Process |
| AIM | Automated Inventory Management System |
| AMSC | American Mobile Satellite Corporation |
| AMVER | Automated Mutual-assistance Vessel Rescue System |
| ANDVT | An HF secure radio handset |
| Ao | Operational Availability |
| ARMS | Automated Requisition and Management System |
| ASAP | Active Stabilized Antenna Pedestal |
| ATM | Asynchronous Transfer Mode |
| AUXMIS | Auxiliary Management Information System |
| BO | Boarding Officer |
| CASP | Computer Aided Search Program |
| CASREP | Casualty Report |
| CDMA | Code Division Multiple Access |
| CGDN | Coast Guard Data Network |
| CI | Consistency Index |
| CO | Commanding Officer |
| COMMSTA | Coast Guard Communications Station |
| COMSAT | Commercial Satellite |
| CP | Contingency Preparedness |
| CR | Consistency Ratio |
| CWG | OSC Communications Working Group |
| DAAS | Defense Automatic Addressing System |
| DAMA | Demand Assigned Multiple Access |
| DO | Defense Operations |
| DOD | Department of Defense |
| EEZ | Exclusive Economic Zone |
| ELT | Enforcement of Laws and Treaties |
| EPIC | El Paso Intelligence Center |
| EV | Eigenvalue |
| FDDI | Fiber Data Distributed Interface |
| FDMA | Frequency Division Multiple Access |
| FLS | Fleet Logistics System |
| G-OCI | Coast Guard Headquarters Office of Intelligence |
| G-OLE-1 | Coast Guard Headquarters Office of Law Enforcement |
| G-SCT | Coast Guard Headquarters Office of Communications Systems |
| GEO | Geostationary Earth Orbit |
| GEOS | Geostationary Earth Orbit Satellite |
| GMDSS | Global Maritime Distress and Safety System |
| GPS | Global Positioning System |
| HEO | Highly Elliptical Orbit |
| HEOS | Highly Elliptical Orbit Satellite |
| HF | High Frequency |

| | |
|---|---|
| HFDL | High Frequency Data Link |
| HQ | Coast Guard Headquarters |
| ICC | Coast Guard Intelligence Coordination Center |
| Intel | Coast Guard Intelligence |
| IP | Internet Protocol |
| JMIE | Joint Maritime Information Element |
| LAN | Local Area Network |
| LEIS II | Law Enforcement Information System version II |
| LEO | Low Earth Orbit |
| LEOS | Low Earth Orbit Satellite |
| LUFS | Large Unit Financial Management System |
| MCDM | Multiple Criteria Decision Making |
| MEA | Mission Essential Applications |
| MEO | Medium Earth Orbit |
| MEOS | Medium Earth Orbit Satellite |
| MEP | Marine Environmental Protection |
| MILSATCOM | Military Satellite Communications |
| MIPS | Millions of Instructions per Second |
| MLE | Maritime Law Enforcement |
| MPRS | Record Message Processing System |
| MSIS | Marine Safety Information System |
| MSN | Marine Safety Network |
| MTBF | Mean Time Between Failures |
| MTTR | Mean Time To Repair |
| NAVCEN | Coast Guard Navigation Center |
| NCIC | FBI's National Crime Information Center |
| NLETS | National Law Enforcement Telecommunications System |
| OGA | Other Government Agencies |
| OIS | Operations Information System |
| OOD | Officer of the Deck |
| OPCON | Operational Commander |
| OSC | Coast Guard Operations Systems Center |
| OSI | Open Systems Interconnection |
| PERSRU | Personnel Reporting Unit |
| PMIS | Personnel Management Information System |
| PPC | Coast Guard Pay and Personnel Center |
| PSTN | Public Switched Telephone Network |
| PV | Priority Vector |
| QIC | Quarter Inch Cartridge |
| RCP | Resource Change Proposal |
| RMS | Record Message System |
| SABR | Sighting and Boarding Report |
| SAR | Search and Rescue |
| SARMIS | Search and Rescue Mangement Information System |
| SCCR | Supply Center Computer Replacement Project |
| SCPS | Space Communications Protocol Standards |

| | |
|---|---|
| SEER | Summary Enforcement Event Report |
| SIPRNET | Secure Internet Protocol Router Network |
| Sitrep | Situation Report |
| SMC | SAR Mission Coordinator |
| SORTS | Status of Resources and Training System |
| SSAMPS | Standard Semi-Automated Message Processing System |
| STAR | Standard Automation Requisitioning |
| SWS-II | Standard Workstation II |
| SWS-III | Standard Workstation III |
| TCP | Transport Control Protocol |
| TDMA | Time Division Multiple Access |
| TECS II | Treasury Enforcement Communications System II |
| TISCOM | Coast Guard Telecommunications and Information Systems Command |
| TQC | Coast Guard Training Quota Control Center |
| UHF | Ultra High Frequency |
| USAT | Ultra Small Aperture Terminal |
| VDOCS | Vessel Documentation System |
| VHF-FM | Very High Frequency - Frequency Modulation |
| VINSON | An UHF secure radio handset |
| VSAT | Very Small Aperture Terminal |
| WAN | Wide Area Network |
| WHEC | Coast Guard High Endurance Cutter |
| WMEC | Coast Guard Medium Endurance Cutter |
| WPB | Coast Guard Patrol Boat |

## ACKNOWLEDGEMENT

The author would like to acknowledge the financial support of the Operations Systems Center, which funded research related travel to both the OSC and TISCOM. This travel was instrumental in conducting an analysis of the current system and obtaining information on current Coast Guard research.

The author would like to acknowledge the funding support provided by Commandant (G-SCT), old G-TTM, for the purchasing of advanced network equipment by the Naval Postgraduate School. This equipment provided valuable, hands-on insight about the local area networks discussed in this thesis.

The author wants to thank Mr. Gordon Shillito for his assistance in obtaining research related travel, and in providing valuable resources on the Coast Guard's communication's requirements.

The author wants to thank LCDR Joseph Lukinich for his assistance in coordinating the visit to the OSC and the valuable information he provided on LEISII.

The author wants to thank Mr. Larry Schimelpfenig for his assistance in coordinating the visit to TISCOM, and the valuable information he provided on Shipnet Plus.

The author wants to thank LT Eugene Vogt for the valuable information he provided concerning the Coast Guard's telecommunication plan.

# I. INTRODUCTION

## A. BACKGROUND

Drugs and illegal aliens continue to filter into the United States. The U.S. Exclusive Economic Zone (EEZ) continues to require protection from encroachment by foreign fishing vessels as well as enforcement support of the fisheries management plans and other regulations which manage and protect our living marine resources.

U.S. living marine resources are managed and protected through an increasingly complex regulatory system of three major statutes and 32 fishery management plans. There are thousands of fishing vessels operating in the U.S. EEZ. The Coast Guard must provide both a deterrent presence, and detect and cite violators, without interfering with legitimate fishing operations. The principal management measures include gear restrictions, closed areas, fishing seasons, and catch restrictions. At times, fishing vessels are allowed to transit closed areas, some attempt to fish in the closed areas. Other fishermen attempt to use illegal fishing gear. The immense size of the fishing grounds, the vast number of fishing vessels, the complexity and number of fisheries management plans, and the difficulty of distinguishing legitimate operators from those not in compliance is a challenge to law enforcement agencies abilities to detect and prosecute violators.

Increasingly, illegal aliens are attempting to enter the U.S., its territories, and other friendly nations through the use a variety of craft ranging in size from an inner-tube to an ocean going freighter. This has required the attention and resources of both Coast Guard Areas. [Ref. 2, pg. 1]

The Coast Guard patrol boats have primary missions of Enforcement of Laws and Treaties (ELT) and Search and Rescue (SAR), and secondary missions of Marine Environmental Protection (MEP) and Contingency Preparedness/Defense Operations (CP/DO). The Coast Guard has been involved in law enforcement since it was established in 1790, which is becoming increasingly more information intensive. Currently the patrol boats do not have the communications necessary to effectively carry out these missions. These limitations must be addressed and corrected if the patrol boat is to be an effective resource.

### 1. Scenario One

The Coast Guard Cutter SAPELO is on patrol off the southern coast of California when the lookout sights a vessel on the horizon. The watch personnel identify it to be a northbound cabin cruiser. The Commanding Officer directs the Officer of the Deck (OOD) to intercept the vessel for identification and possible boarding. Once close enough, Cutter SAPELO's bridge personnel obtain the name and hailing port off the vessel's stern and begin pre-boarding questions using the VHF-FM radio. In the meantime, the Law Enforcement Petty Officer conducts LEIS II tactical queries on the vessel and operator using a virtual X.25 connection with the OSC. Within a few minutes, the central LEIS II database responds that the vessel is on the NCIC's stolen boat report and that the operator has several outstanding warrants in the state of California and is considered "armed and dangerous". The SABR query indicates that the vessel has not been boarded by the Coast Guard in 5 years. In the meantime, the vessel's operator states that he was boarded 3 weeks ago by the patrol boat out of San Diego and is out on an offshore fishing trip with two of his "buddies". The Commanding Officer decides to board the vessel and briefs the boarding team on the inconsistency of the operator's response and the possible dangers involved in the situation.

If this scenario took place today, the patrol boat would have let this vessel continue on its way because there would not have been information available from NCIC or NLETS, and the SABR information on the local LEIS II database would have been presumed to be out of date. The operator would have been given the benefit of the doubt and the cutter personnel would have assumed that the boat was boarded by the San Diego based cutter, and that the boarding information just didn't make it into the latest download of SABR Long List report. The patrol boats have no means of effectively querying the LEIS II central database while underway. Some patrol boats do request LEIS II queries through their supporting OPCON, but the results of the query are usually not received until after the boarding has commenced, or the target vessel is no longer in the area. This leads to missed boarding opportunities and unsafe boarding conditions as boarding teams conduct boardings with insufficient background information on the vessel and operator. This thesis will evaluate the current system and recommend a system which will meet the patrol boat's near-term requirements.

### 2. Scenario Two

The Coast Guard Cutter MUSTANG is directed to divert and intercept a foreign flagged vessel suspected of carrying illegal aliens. As the Cutter arrives on scene, a crewman is assigned to videotape the suspect vessel. Cutter MUSTANG attempts to communicate with the vessel which appear to be ignored or not understood. The Cutter closes within several hundred yards in an attempt to visually communicate with the vessel and better assess the vessel. As the Cutter closes, several hundred people are observed and videotaped coming out on deck and waving their hands. At the same time gunshots are fired at the cutter from the vessel's bridge wing and the vessel makes a sharp turn toward the Cutter. The Cutter MUSTANG maneuvers at high speed to avoid the vessel and get out of range of the gunfire. The Cutter MUSTANG takes station several miles astern the vessel and contacts the Coast Guard Command Center to brief the senior controller on the current situation. A video conference call is established and the Commanding Officer of the Cutter MUSTANG provides the Command Center with a verbal brief of the situation and plays the videotape clearly showing the Cutter's approach on the suspect vessel, the personnel, the gunshots, and the vessel's attempt to ram the Cutter MUSTANG. The Command Center uses a copy of the videotape to obtain a "Statement of No Objection" from the country the vessel claims as its flag. It also uses the videotape to brief three other cutters being diverted to assist.

Long-term reality: The use of video and imagery has tremendous potential in most mission areas and has proven valuable as trial evidence. Its use on board Coast Guard cutters will require relatively inexpensive, high-bandwidth mobile communications systems providing coverage over all of the Coast Guard's operating areas. There are systems available today which can provide this type of service, but their implementation is either too costly, or not suitable for use on a patrol boat. This thesis will look at two proposed systems which may meet those needs.

## B. OBJECTIVES

There are three objectives of this thesis: conduct an analysis of the near and long-term communications requirements for the Coast Guard patrols boats, investigate current and future communication systems which may meet the patrol boat's requirements, and recommend a system that allows the patrol boat to effectively communicate with both the cutter's operational commanders and the Operations Systems Center (OSC). Design will

consist of a proposed communications system which will allow access to the Coast Guard Data Network (CGDN) while underway on patrol, particularly the ability to conduct queries on the central Law Enforcement Information System (LEIS II) database. The proposed solution will be compatible with both the current CGDN, and the Coast Guard's future intranet.

## C. SCOPE, LIMITATIONS AND ASSUMPTIONS

The scope of this thesis is limited to the interaction between the underway patrol boat and the OSC, because of its increasing role as the central source for all operational and support related data. The importance of the patrol boat's ability to communicate with its operational commander and the servicing communications station, however is not negated, and should be enhanced by the capabilities added by the recommended solution.

The patrol boats are unique because of their size and weight restrictions, significantly restricting the number of viable alternatives. Of the viable alternatives, several are only proposed systems and have yet to be implemented. The cost and capabilities of those proposed systems are estimated for the purposes of analysis. It is assumed that the Coast Guard will continue to replace the installed base of SWS-II computers with SWS-III computers, and that the CGDN will be upgraded to support current local and wide area network standards.

## D. METHODOLOGY

The methodology used for this research includes a survey of the existing literature on satellite communications, a survey of current Coast Guard research on satellite communications, interviews with numerous personnel involved directly or indirectly with the patrol boat or satellite communications, and browsing the Internet for the latest information in this rapidly evolving field. Personal experience as senior Boarding Officer, Executive Officer and Commanding Officer of a Coast Guard patrol boat was applied to this research. The model of the Coast Guard's "Shipnet Plus" program was used as the patrol boat's desired concept of operations.

## E. ORGANIZATION OF STUDY

This chapter is the introduction to the study. Chapter II provides an analysis of the current state of the patrol boat and the OSC. Chapter III presents the near and long-

term requirements and develops the target system architecture. Chapter IV contains a literature review of current Coast Guard research and an overview of the most promising satellite systems. Chapter V provides recommended solutions using AHP. Finally, Chapter VI presents the conclusions and recommendations of this study.

# II. THE EXISTING SYSTEM

## A. INTRODUCTION

The patrol boat has an important communications relationship with the OSC. The OSC maintains all of the Coast Guard's centrally managed operational databases including LEIS II and SARMIS. With LEIS II, they also provide the gateway to access the NCIC, NLETS, and MSIS/VDOCS. Figure 1 shows the basic relationship between the users of LEIS II and the OSC. Inport, the patrol boat uses the CGDN to obtain administrative and operational data. Once underway, the patrol boats lose connection to the CGDN and have no effective means to access the OSC's databases.

The Coast Guard's current data network, the CGDN, is the primary means for transmission of non-secure Coast Guard shore-side data communications. CGDN connects virtually every shore facility and the vast majority of cutters when moored in their home port.

The CGDN uses the X.25 protocol switches off the FTS2000 contract, with the backbone switches located at each of the continental U. S. District Offices, the OSC, and Coast Guard Headquarters. Redundant links are maintained to provide a high level of availability.

The major applications that pass data over the CGDN include MSIS, LEIS II, PMIS, and e-mail. E-mail is extremely important because many applications use e-mail envelopes to transmit application specific information from point to point. The CGDN uses e-mail as the transport mechanism to support file transfer in applications such as LUFS and PMIS. [Ref. 14, Deliverable 2, pg. 8]

## B. THE COAST GUARD PATROL BOAT

The patrol boat is a multi-mission platform that is unique because of its small size and broad operational requirements. Its primarily missions are ELT and SAR, but it may also be assigned port security and marine environmental protection duties. There are currently two classes of Coast Guard patrol boats: the 82 foot and the 110 foot WPB. Both are assigned similar missions but the 110 foot WPB has better operating characteristics and communication capabilities.

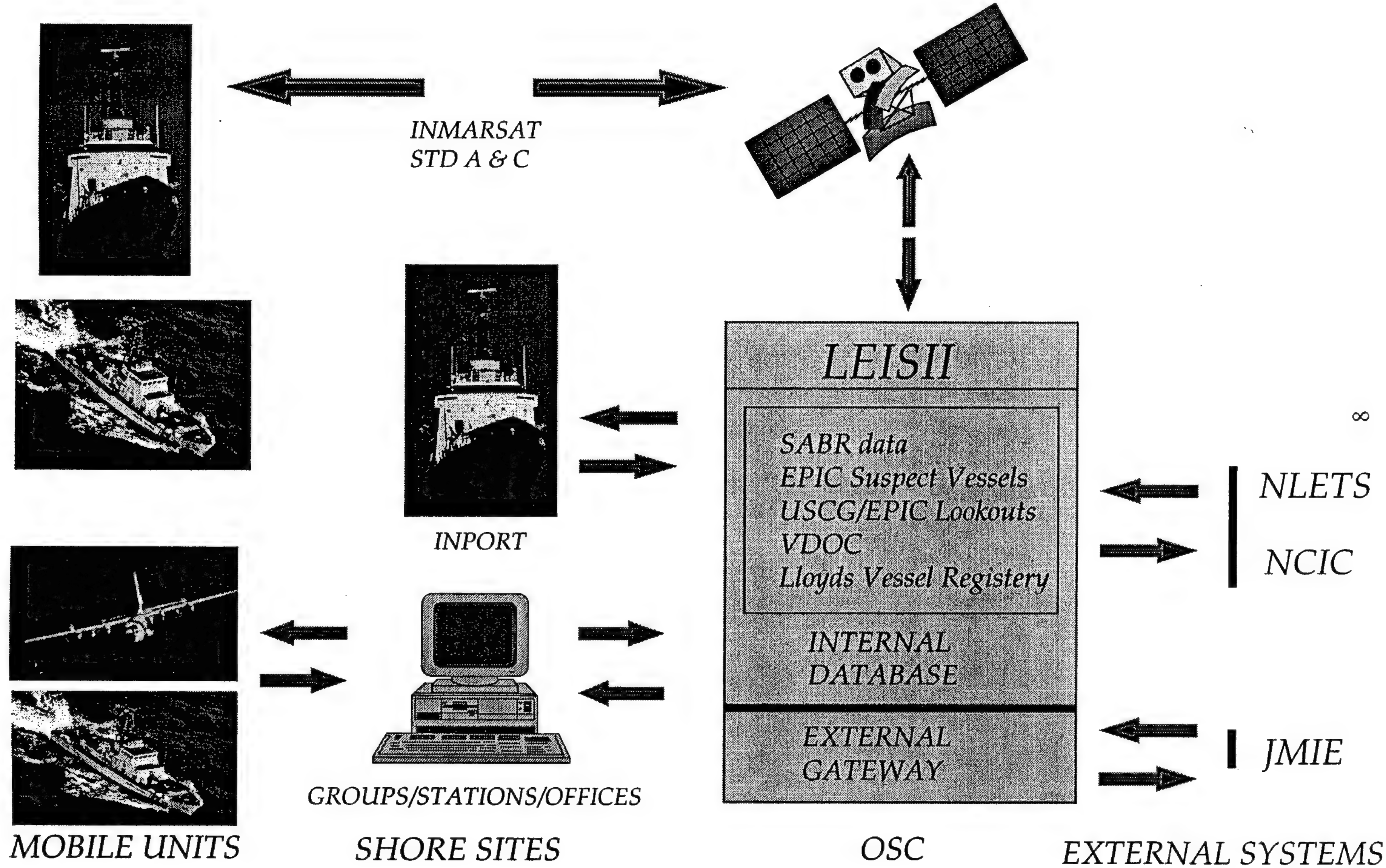


Figure 1. LEISII "One-stop Shopping". From Ref. 4, pg. 13

The patrol boat's ability to communicate is determined by its location and operational status. Figure 2 shows the typical patrol telecommunication system. When moored at its homeport or another Coast Guard command, the patrol boat has access to the CGDN through a physical 9.6 kbps connection that links them to either their Group or District Office, which in turn connects them to the CGDN. Each patrol boat has several telephone lines connected to the boat to support voice, fax, and a dedicated line for data. The connection to the CGDN provides access to numerous administrative and operational systems including: LEIS-II, FLS, SSAMPS record message traffic system, STAR/ARMS, e-mail, SARMIS, and LUFS. Besides the connectivity provided by access to the public telephone system, the patrol boat also has access to the satellite, radio and navigational systems principally used when underway.

Underway, the patrol boat loses access to the CGDN and the corresponding administrative and operational data it provides. Transmission of text-based record message traffic is shifted from the CGDN to an High Frequency Data Link established with one of the two Communications Area Master Stations. Voice communications are conducted using UHF, VHF-FM and HF radio. Secure communications are available using HFDL, UHF VINSON, and HF ANDVT. Receive only data capability is provided by an INMARSAT C terminal which is used to provide the ship with weather and Notice to Mariners information. The majority of the patrol boats are also equipped with cellular telephones, however, they are not authorized nor supported by the current Coast Guard Telecommunication Plan.

### 1. Law Enforcement Mission

The patrol boat's most important and data intensive mission is law enforcement. Strategic and tactical law enforcement data is provided by LEIS II, which is maintained by the OSC. LEIS II contains the only functional tactical query system available to the patrol boat that can provide the commanding officer with near real-time tactical data. Because the patrol boat cannot receive data underway, it relies on the limited amount of strategic data it can obtain from LEIS II prior to getting underway.

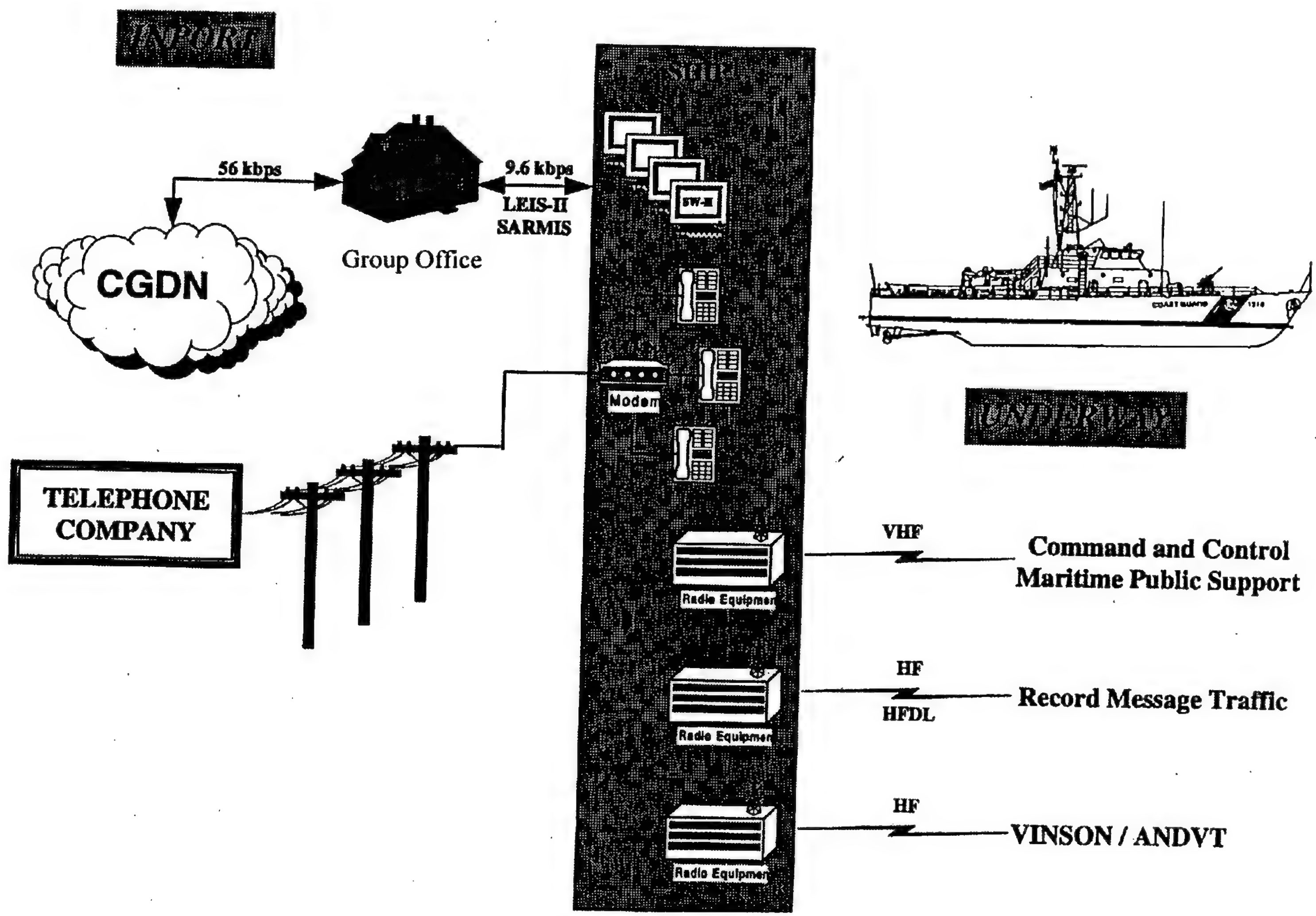


Figure 2. WPB Telecommunications System. From Ref. 14, Deliverable 2, pg. 28.

*a. Procedures*

The LEIS II application runs can run off either a local system maintained on board the cutter, or off the central computer system at OSC. Since there is no data connection available to the WPB, the local system is updated prior to getting underway for patrol. The information maintained on the local system is stream-lined and nowhere near as complete as the information on the central computer. The local system contains the LEIS II data entered by the WPB along with any additional information request from OSC. The additional information OSC provides is limited to information about vessels boarded in the last 3 to 6 months, depending on the size of the coverage area requested, and the latest El Paso Intelligence Center (EPIC) lookout list.

Underway, the patrol boat must rely on the information available in its own local file system, or what it can obtain from shore units. Prior to boarding a vessel, the patrol boat will conduct a pre-boarding questionnaire and search its local system for any information. If no information is available from the local LEIS II file system nor unit maintained LE information, and the vessel fits a profile for illegal operations, the WPB may ask the supporting Group Office or Communications Station to conduct an "EPIC check" on the vessel and operator. This entails providing the Group or Communications Station with specific information so that EPIC can check its records for any past suspicion of illegal activity. A general law enforcement boarding is normally conducted as follows:

1. Locate vessel.
2. ID vessel and conduct pre-boarding questionnaire.
3. Conduct LEIS-II check using on-board local database.
4. Call Operational Commander for EPIC check.
5. CO evaluates boarding opportunity.
6. Set Law Enforcement Bill, assign boarding team, get small boat ready to launch.
7. Brief boarding team about vessel.
8. Conduct boarding of vessel - primarily safety and documentation.
9. Boarding complete, return to cutter.
10. Debrief boarding team.
11. Secure from Law Enforcement Bill.
12. Draft required reports (i.e. sitreps, SABRs and boarding reports).

The boarding process takes about one hour to complete after Law Enforcement Bill has been set. Ideally the boarding team will have the results of both the LEIS II query and the EPIC check prior to getting underway. This is usually not the case. Because of the limited amount of data available in the local LEIS II system, the tactical query only provides information about a particular vessel 25% of the time. It is also contains significantly less information than what is available from the central computer system at OSC. Occasionally the WPB will have the Group or Communications Station conduct the LEIS II check. The Group and Communications Station have access to the central computer at OSC over the CGDN and can provide much more extensive information. The problem is the time and coordination needed to conduct such a query.

About 25% of the boats boarded have EPIC checks conducted on them, the boarding party does not normally wait for a reply prior to boarding. If the EPIC check comes back "negative" while the boarding is in progress, the cutter rarely passes on the information to the boarding team. If the check comes back "positive", most WPBs pass code words over the radio to the boarding teams to alert them of possible threats or illegal activity. About 50% of the responses to the EPIC check are received prior to the completion of the boarding.

### *b. Crew Safety*

Boarding team safety is a key concern during the boarding evolution. While the boardings are conducted professionally and the boarding teams are well trained in law enforcement, there is valuable information available from the central computer at the OSC that can enhance the team's ability to conduct a more safe and thorough boarding. The added information would provide the Commanding Officer and boarding team with more detailed information concerning an operating area, a particular vessel, or the vessel's crew than is available from the LEIS II database maintained on the ship.

More complete and timely information will impact the boarding process by assisting the Commanding Officer in the board/don't board decision process, and will better prepare the boarding team by allowing them to be more prepared for the boarding. This preparation will provide a heightened sense of awareness while on board the vessel, which directly relates to team safety. The boarding team can also run NLETS and NCIC checks on suspicious crewmembers during the boarding.

### 2. Hardware

#### *a. Systems*

The primary computing and communications platform on board the patrol boat is the Coast Guard Standard Workstation II (SWS-II). It consists of Unisys proprietary workstations running the Unisys CTOS operating systems. The SWS-II computer is a 386/16 MHz or less CPU capable of being networked in a "thin client" manner. The master workstation typically has up to two 105 Mb hard disks and contains all of the applications and data used on the cutter. Up to 16 additional workstations (48 if properly licensed) can be connected to the master. These clustered workstations may have their own local file storage available, but typically the clustered workstations only contain a monitor, keyboard, CPU and floppy drive. The patrol boats typically have three SWS-II terminals available for administration, supply, and operational support, and the 110 ft patrol boats have an additional SWS-II terminal for sending and receiving record message traffic using the HFDL. The 82 foot WPB does not conduct any record message traffic underway and carries a limited SWS-II computer for operational and administrative use. The communications port of the Unisys workstation is limited to 9600 bps. Over the next several years, SWS-II computer systems are being replaced by SWS-III systems, which consist of at least 75 MHz Pentium computers running Windows NT.

Data communications is rarely conducted by underway patrol boats, and is not possible using the current HFDL system. HFDL is the method used to transmit record message traffic to and from the underway 110 foot patrol boats. The SWS-II computer running the HFDL control software is a standalone "Secret High" system which is physically separated from the other SWS-II computers on board. The system is not capable of declassifying data for transfer to the administrative SWS-II, which supports the LEIS II application. Most 110 foot WPBs also have INMARSAT C installed, but are only authorized to receive navigational safety and weather information. Several patrol boats operating in Alaskan waters have been authorized to both transmit and receive data using INMARSAT C, however it is only intended to access a local fisheries database. The 82 foot WPBs have no means of conducting data communications.

The patrol boats have limited long and short range communications capabilities. They typically have a GSB900 HF system, a MCX 1000 VHF-FM radio, a second commercial VHF-FM radio and the 110s have a WSC-3 UHF radio. Secure

communications is conducted using the installed ANDVT (HF), VINSON (UHF - 110s only), and HFDL (using KG-84 - 110s only). As mentioned previously, most cutters do carry unit funded cellular telephones, which are not authorized by the current Telecommunications Plan. [Ref. 14, Deliverable 2, pp. 28-29]

### *b. Availability*

Availability of the current voice communication systems are enhanced by designing redundancy into the system. Redundancy is only provided for primary communications systems, which includes HF and VHF communications. Besides redundancy, availability is also improved by providing battery backup to certain critical communications and navigation systems including both VHF-FM radios, the gyrocompass and the loran C receiver. Redundancy is built into the HF system by having two GSB900 transceivers with a patch panel to assign the two HF couplers to any of 3 remote stations. The computer system that runs the HFDL software is also modular, allowing for the replacement of the system by the WPB crew. If a computer component does break down, the system administrator simply replaces the defective component with an on board spare, and sends the defective component in for repairs upon return to port.

Shifting to backup systems is the primary method available for the patrol boat crew to keep a system operational. There are no Electronics Technicians assigned, so underway repair of electronics equipment is rarely conducted. Normally, the Commanding Officer, guided by additional resources like the Status of Resources and Training System (SORTS) job aid, makes the determination of whether the failure warrants terminating a patrol. If the failure is significant, or creates a longer term reduction in capabilities, the cutter will issue a Casualty Report (CASREP) and adjust its SORTS status. While these reports do identify problem areas, they do not contain enough failure data to determine what the actual availability of systems is. Interviews have indicated that tertiary communications systems like INMARSAT C are the most likely to fail because they do not receive adequate preventive maintenance.

### *c. Security*

There are several encryption methods used on the patrol boats, but none provide protection for the transmission of data packets underway. Inport, X5000 DES encryption is used to ensure the security of sensitive but unclassified information

transmitted over the CGDN. The patrol boats also use the data capability of the STU-III telephone to transmit secret data when inport. Underway, the encryption of data is not available, but the encryption of voice and message traffic is. HFDL message traffic is encrypted using a KG-84. This provides for the transmission of messages classified up to the secret level. Secure voice encryption is provided using ANDVT for HF, VINSON for UHF, and DES for VHF-FM radio communications. The INMARSAT C system is not designed to work with encrypted data. The remainder of the communication systems used by the patrol boat are strictly for unclassified traffic.

## C. OPERATIONS SYSTEMS CENTER

The OSC was designed and constructed to be a state-of-the-art computer support facility able to accommodate all of the Information Resource Management (IRM) needs of the Coast Guard. With the advent of Government open systems standards, the OSC was also designed for sharing of system resources among many applications for maximizing flexibility and minimizing costs, both recurring and non-recurring, and for implementing and supporting those systems.

Prime computers (6-12 MIPS each) provide support for mission critical applications such as AMVER, MSIS, LEIS II, and CASP. A TP-5, which is linked to a TP-4 in the COMMCEN, is used for the CGDN. Other mission essential applications run on various OSC mini-computers.

OSC maintains a 24-hour operation where several telecommunications circuits, including EasyLink, CGDN, and secure FAX provide messaging service for OSC operations and administration. They use SSAMPS with the new MPRS to process record message traffic to the desktop. Their equipment suites includes SWS-II and SWS-III computers, cryptographic equipment, and a TP-4 telephone switch. In addition to processing message traffic, they monitor several circuits, with emphasis on AMVER messages where they watch closely for requests for Search and Rescue assistance. They will soon be migrating to broadband TCP/IP. [Ref. 14, Deliverable 2, pp. 32-33]

### 1. Mission

OSC develops, fields, maintains, and provides user support for major operationally focused information systems and data bases that are accessible to the Coast Guard around the clock from around the world. These systems serve as the information

heard of the Coast Guard's SAR, law enforcement, marine safety, and logistics support functions. OSC also serves as the network control center for the Coast Guard's wide area data network and carries out the Automated Information System risk analysis program for other data centers and major mission critical software development projects.

### 2. Supported Software Applications

Figure 3 shows a list of several Mission Essential Applications (MEA) supported by the OSC. Of those, only a few are directly accessed by the patrol boat: LEIS II, SARMIS, and STAR/ARMS.

#### *a. LEIS II*

LEIS II is the primary tactical and strategic law enforcement application used by the Coast Guard. It is installed at over 450 shore-based and shipboard units in support of the Law Enforcement mission. The central LEIS II database contains the following:

- Several years of sighting and boarding data provided by all the Coast Guard cutters and aircraft.
- The current EPIC Suspect Vessel lookout list.
- The current U.S. Coast Guard lookout list.
- Summary information from the MSIS/VDOC database.
- Lloyds of London Registry information.

LEIS II also provides access to external systems which include the FBI's NCIC and NLETS. The NCIC contains information on stolen boats, felony wants and warrants, criminal history, and weapons. NLETS is a network connecting federal and state computer systems and providing access to Canadian national and provincial systems. NLETS contains identification information on vessels, people, vehicles, articles, aircraft registrations and sightings, weapons, and hazardous materials. [Ref. 6, pp. 1-7 to 1-8]

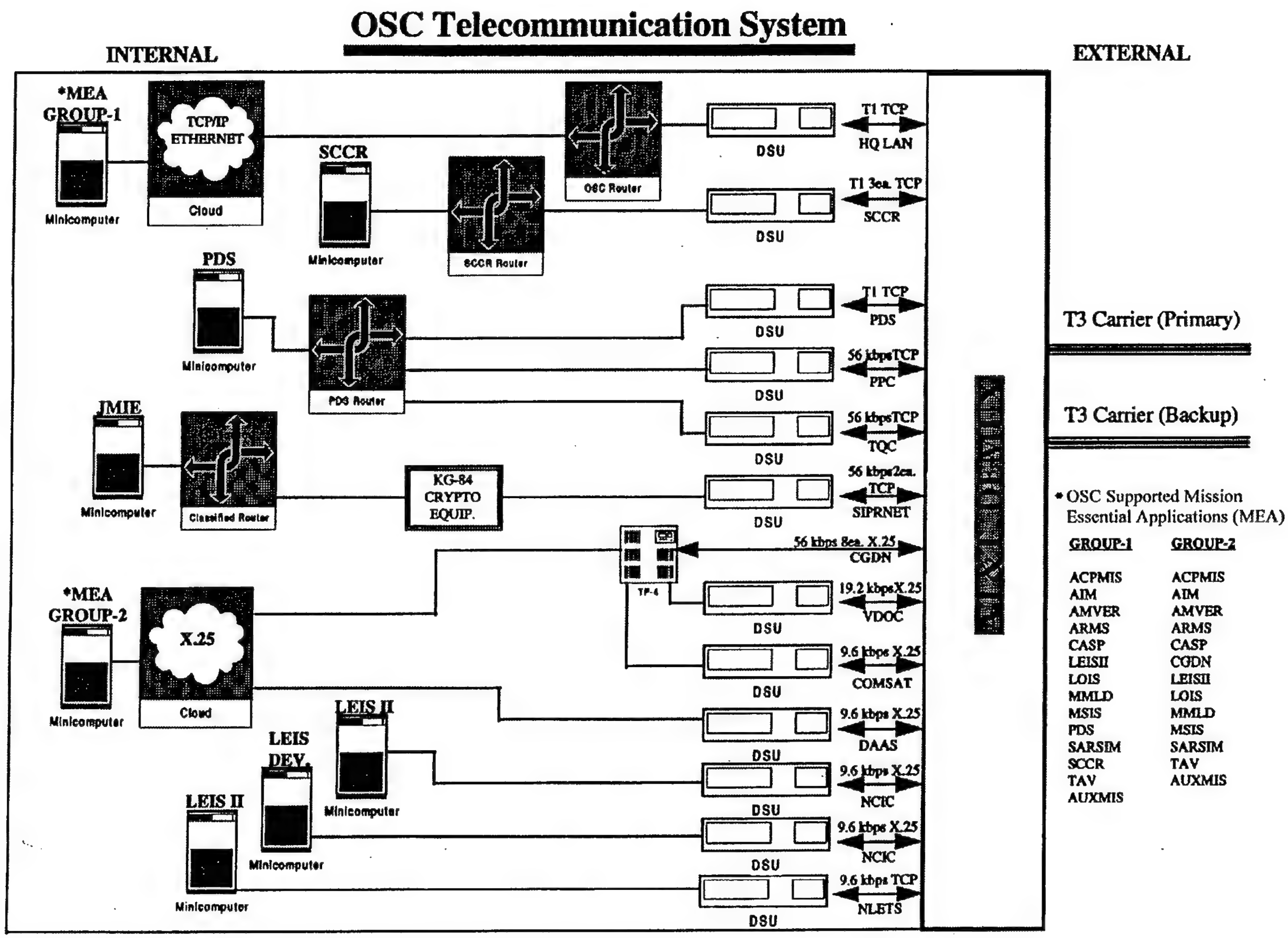


Figure 3. OSC Telecommunications System. From Ref. 14, Deliverable 2, pg. 32.

Several methods to access the information is provided to support the many users. Local databases are updated either through a direct connection, overnight quarter inch cartridge (QIC) tape, or through record message traffic which must be manually entered. Direct communications with OSC can be supported using one of the following methods:

- CGDN X.25 or Virtual X.25 dial-up
- E-Mail
- Asynchronous Dial-in
- INMARSAT A & C
- Record Message System (RMS)
- QIC tape

Figures 4 and 5 show the LEIS II Concept of Operations and the LEIS II Data Communications Channels. Onshore, connection is usually established over the CGDN X.25 network, which provides a 9600 baud connection. Virtual X.25 provides a 2400 baud connection for smaller shore units and is part of the Shipnet Plus initiative discussed later in this chapter. INMARSAT A is used by larger cutters and supports either the Virtual X.25 dial-up or the Asynchronous dial-in at 2400 baud. The cutters currently using INMARSAT A for their transmission medium do not have the required equipment to transfer encrypted data using LEIS II. LEIS II can be used over INMARSAT C, however it has not been used other than for testing. The data is transmitted using a store and forward queuing systems at 600 baud. RMS is only used for the submission of the SABR.

The patrol boats provide data submission to both the central LEIS II system and their own local database through use of the SABR. The SABR is a formatted message containing information on detections, sightings, boardings, and associated information on vessel and people violations. Timely and accurate submission of the SABR report provides other units with current Coast Guard law enforcement information for a geographic region or a specific unit.

There are several reports produced by LEIS II which can be broadly categorized as either tactical or strategic. The tactical reports focus on a specific boat or person and consist of: the Lookout Check for a particular person or vessel, the ID Check for a particular vessel, and the SABR Check for a particular vessel. List reports are

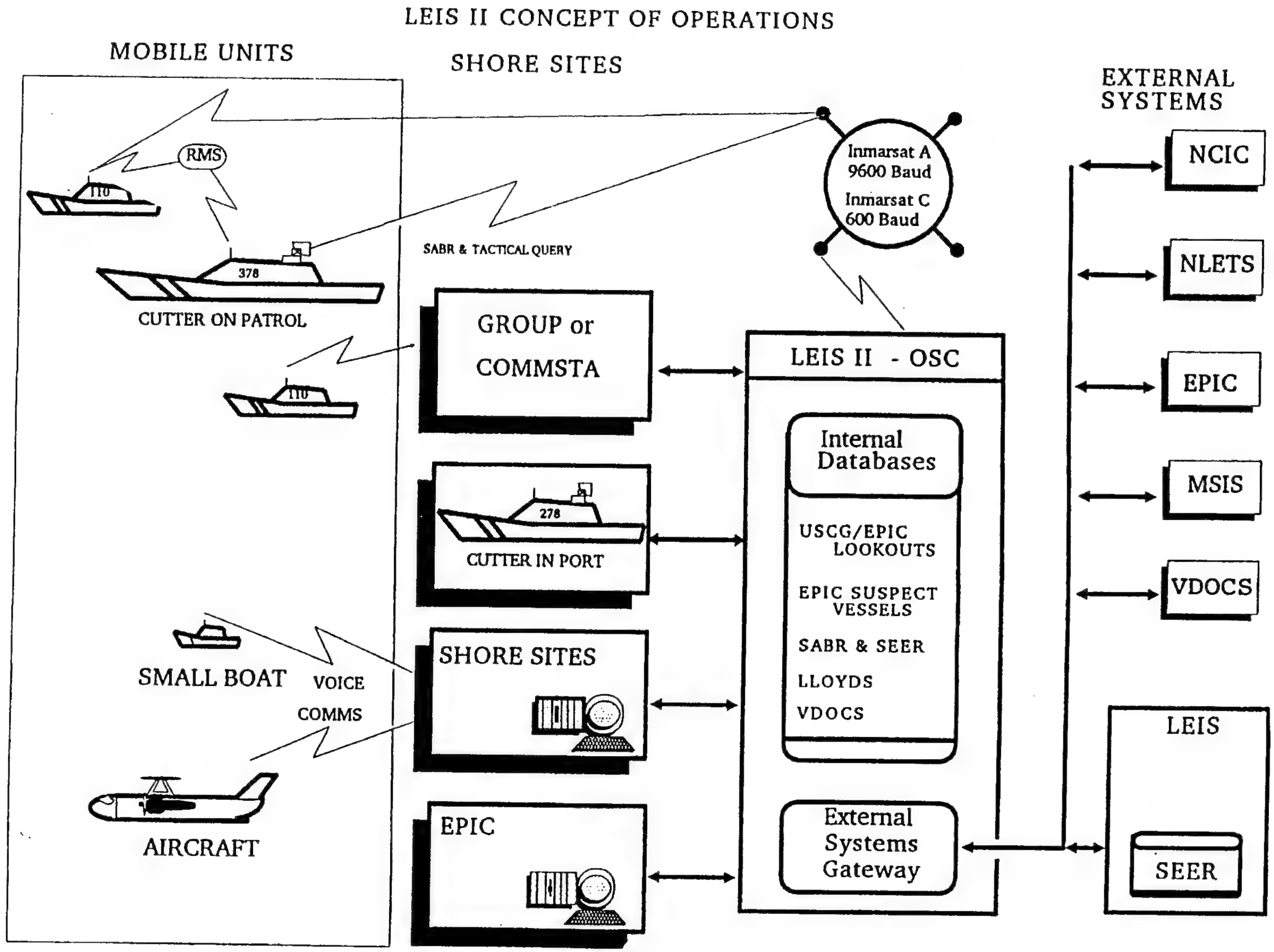


Figure 4. LEIS II Concept of Operations. From Ref. 5.

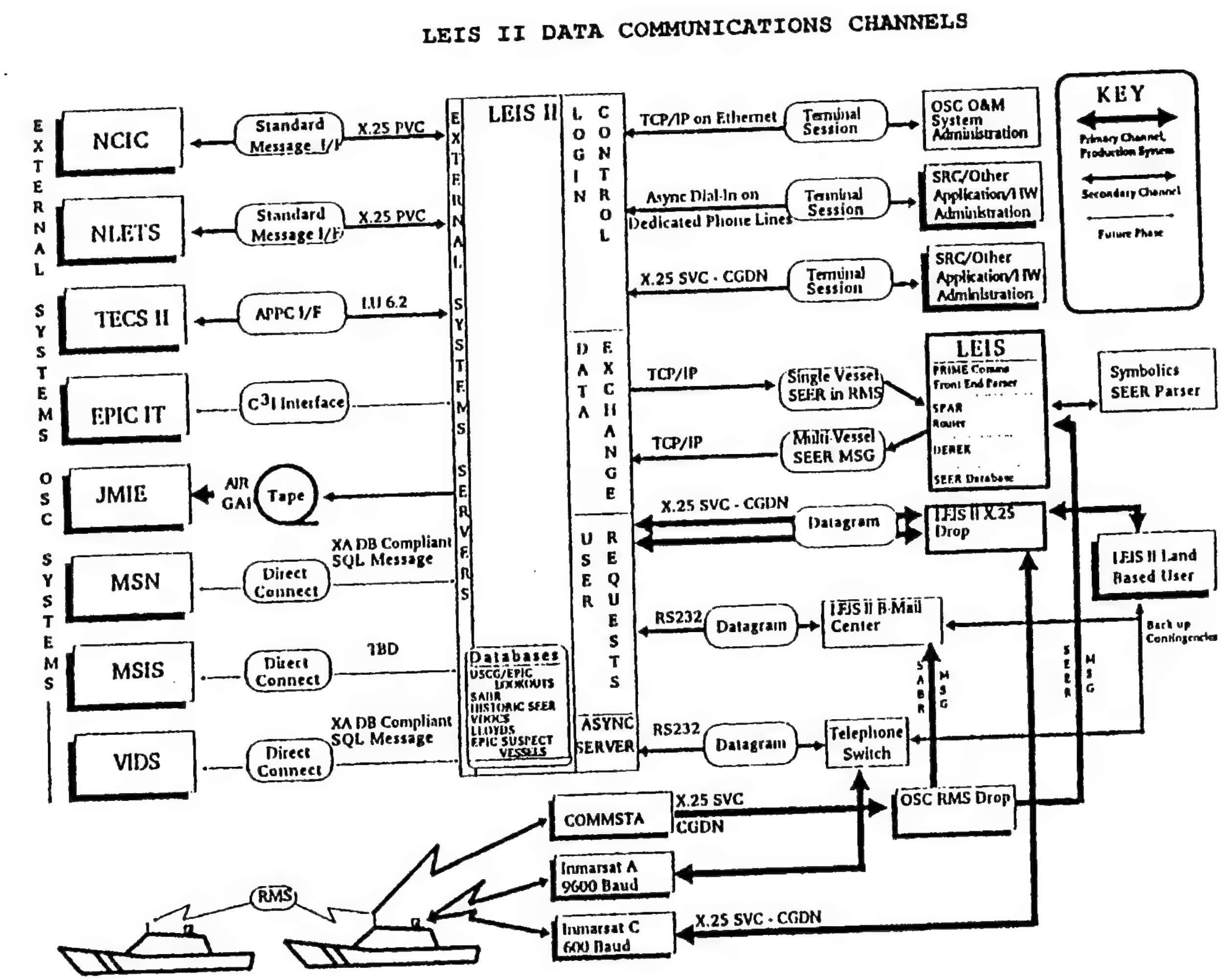


Figure 5. LEIS II Data Communications Channels. From Ref. 5.

considered more strategic because they provide information on groups of vessels that meet the selection criteria identified in a query. The list reports consist of "long" and "short" multi-vessel SABR Lists, and the current EPIC Lookout List. The patrol boats generally use the long multi-vessel list to populate their local LEIS II databases. A typical long list contains about three months of detailed SABR boarding information for a specific geographic area. The data provided by the long list is then queried using the SABR Check prior to boarding a particular vessel. [Ref. 6, pp. 1-4 to 1-7]

#### *b. SARMIS*

The Search and Rescue Maritime Information System (SARMIS) contains summary information about all of the SAR missions conducted by Coast Guard units. After each SAR case, the responding unit is required to submit a SARMIS report. The report is formatted according to the database requirements and contains summary information about the case. The consolidated data at OSC is used to provide valuable statistics about the Coast Guard's Search and Rescue efforts including the number of lives saved or assisted and the value of the property saved.

#### *c. STAR/ARMS*

The OSC maintains the central ordering database for the Automated Requisition Management System (ARMS), soon to be replaced by STAR. ARMS is used to order parts and equipment through the government supply system. ARMS provides the user with a means of placing and tracking the order. The cost of the order is then automatically subtracted from the units budget.

### 3. Expanding Mission

#### *a. Shipnet Plus*

The Shipnet plus project is designed to provide CGDN connectivity to cutters both underway and inport. The project was originally designed to provide CGDN connectivity to inport cutters which do not have access to the CGDN. Early on INMARSAT A was added to provide underway access to OSC applications such as LEIS II and STAR. Since the majority of patrol boats do not have satellite communication

capabilities, Shipnet Plus is currently not available to them. Figure 6 shows a graphical overview of the Shipnet Plus concept.

The system consists of 24 modems physically connected to three X.25 switches. The number of modems originally planned to be supported was based upon the total number of cutters 210 feet and larger (43). By adding a CPX-10 switch, an additional 48 modems can be supported, however, only 15 phone lines are available and the procurement of additional lines is restricted due to construction of new buildings near the OSC. The current modems can support 28.8 Kbps. using synchronous dial-up. However, even though the modems can support data rates that high, the SWS-II's communications port is limited to 9.6 Kbps The connection from the X.25 switches to the TP-4 is currently running at 9.6 Kbps, but can be upgraded to 56 Kbps with little effort. The equipment, and use of X.25 requires that the cutters be allocated a specific modem. Dynamic assignment of modems as is common with ISP type operations is not available.

Inport, the cutter gains CGDN access from wherever it can access a commercial telephone line. Underway, it gains access to OSC supported applications (i.e. LEIS II and STAR) via INMARSAT A. At the discretion of the Commanding Officer, underway connection to the CGDN via INMARSAT A is possible.

The inport connection to CGDN relies on dial-up (VooDoo) X.25 technology. A hypothetical connection from the ship to the Area office is conducted as follows:

- E-mail generated on the cutter is queued for transmission. The Email application sees that the piece of mail is destined for an X.25 address. This causes the modem to go high and dial a number programmed in memory.
- The modem dials up the modem connected to the TP3 concentrator at the Area office (home port on the drawing). When the Area modem auto-answers the call, a synchronous connection is established between the ship and the Area. This connection looks no different than a synchronous connection over dedicated circuits.
- The X.25 call is routed from the concentrator through the CGDN network to the e-mail destination. The e-mail is exchanged just as if the ship was connected to the CGDN by dedicated circuit.

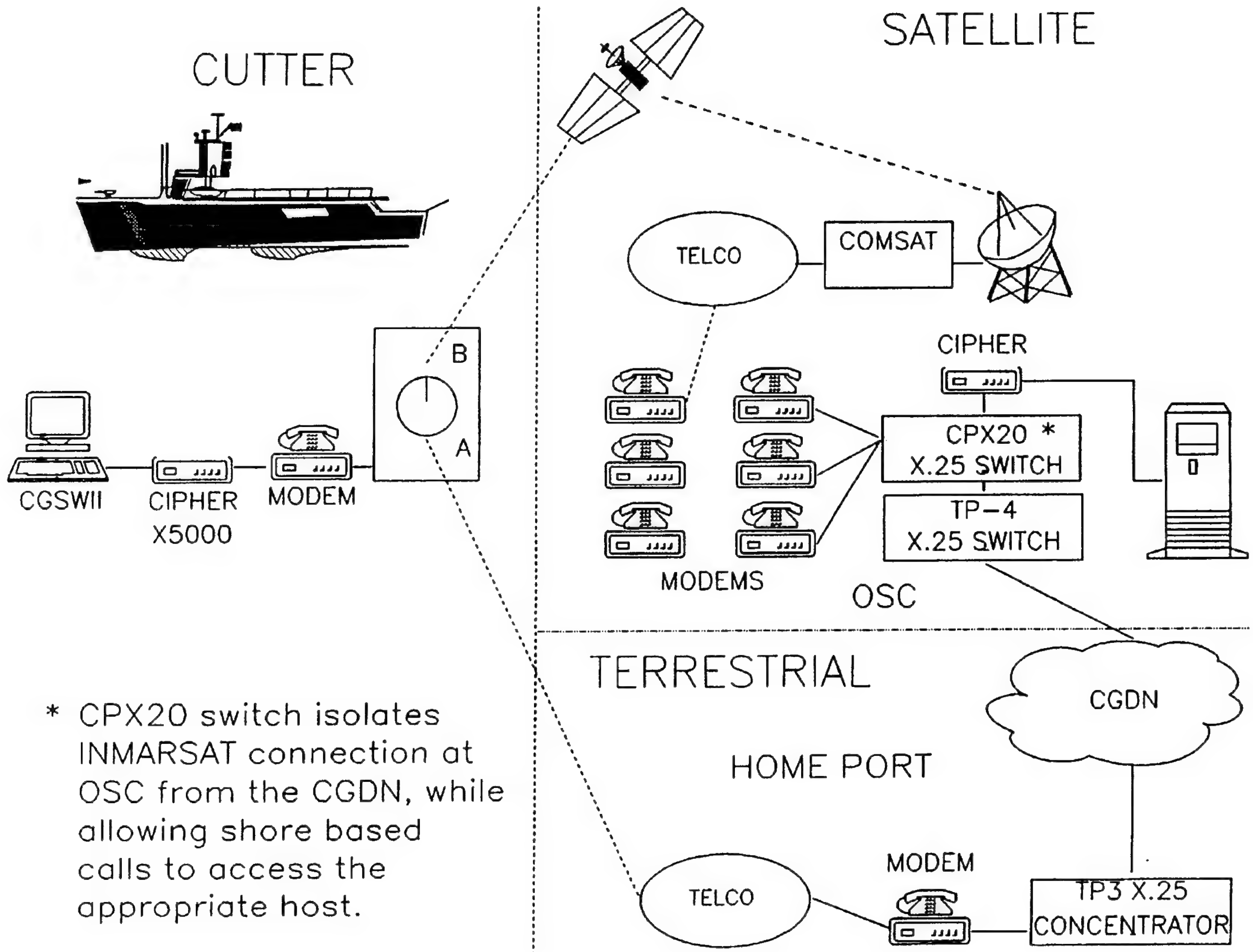


Figure 6. Shipnet Plus model. From Ref. 7, pg. 3.

- E-mail will continue to be transmitted until the queue is empty. As the e-mail is being delivered, other users may simultaneously be using the system to do ARMS transactions or other functions. As soon as the last e-mail is sent or the ARMS function is completed, the modems will automatically disconnect.
- Should the Area desire to send something to the ship, the process is repeated, however the modem at the area initiates the call.

Connecting to OSC using INMARSAT is a little different. Typically the cutter is underway, but the connection can be conducted in port.

- The ship completes an LEIS II query and the modem which is now connected to the INMARSAT terminal and programmed with a different telephone number dials the assigned modem at OSC. The specific phone numbers are assigned to the cutters by the OSC.
- Once the ship's modem connects with that at OSC, the data is routed through a CPX20 X.25 switch directly to the host computer.
- The host may have an immediate response, in which case the transaction will be completed with one call. If it takes some time to collect the data, the host may disconnect, and reestablish the connection once it has the information.

Connecting to the CGDN using INMARSAT-A is similar to the connection with OSC described above, however a third telephone number must now be stored in the ship's modem, and through INMARSAT it dials the number of the modem connected the TP3 back at the Area.

It was decided that the most cost effective solution for CGDN connection while inport is to use a local telephone number. Since the primary use of this connection would be while in homeport, it was projected that a local number would be more cost effective than a 1-800 number. As a result the first expense issue would be the telephone call from a foreign port back to the modem. The program managers for LEIS II (and possibly STAR) have received funding to cover INMARSAT charges associated with their applications. OSC keeps track of the time used. However, if the cutter chooses to use the INMARSAT connection to CGDN, the ship is responsible for any INMARSAT charges. [Ref. 7, pp. 1-2]

### *b. Program Support*

The OSC is becoming the central repository and clearinghouse for the majority of Coast Guard managed data. In addition to the applications and their respective data repositories listed above, OSC will become responsible for several more key applications within the next few years. These include responsibility for both the Personnel Management Information System (PMIS) and the Fleet Logistics System (FLS). The inclusion of PMIS is especially significant since it has recently been expanded to include the data from all previously maintained administrative databases. Along with PMIS, OSC will also be responsible for maintenance of all medical data. The move of PMIS to OSC will add to the requirement that patrol boats be able to access data at OSC at anytime from anywhere since there is an effort to eliminate Personnel Reporting Units (PERSRUs) as applications are pushed back to operational units. [Ref. 14, Deliverable 3, pp. 22-24]

Besides added application support, OSC is intended to be the gateway for access to computer based training which will provide interactive video, graphics and sound to the user's desktop. Headquarters, Area, and District Command Centers also plan on using OSC as the gateway for obtaining the tactical picture during major operations. This will include video and imagery during LE and SAR. Automated chart updates are also to be provided from NAVCEN through OSC. [Ref. 14, Deliverable 3, pp. 8-15]

## D. SUMMARY

The patrol boat is currently unable to effectively exchange operational data while underway on patrol. This significantly reduces the effectiveness and safety of the cutter's law enforcement boardings, and restricts the availability of LEIS II, which is a valuable law enforcement decision making tool. Chapter III builds upon the analysis conducted in this chapter by developing the patrol boat's future mission requirements and target system architecture. The concept of operations for the patrol boat's target system architecture is similar to the Shipnet Plus project, but tailored for the patrol boat.

# III. THE TARGET SYSTEM

## A. SYSTEM REQUIREMENTS

There have been several studies conducted by the Coast Guard within the last few years which have identified requirements for the Coast Guard's cutters future communications systems. The two most directly related to the patrol boat were generated by Headquarters Office of Law Enforcement (G-OLE-1) in 1993 as part of the Data/Communications System Tactical Operational Requirements, and by the Headquarters Office of Communications Systems (G-SCT) as part of the current draft to the Coast Guard Telecommunications Plan. The majority of the requirements mentioned by those two sources are summarized in this chapter under section A.2 (Long-term Requirements).

The requirements are separated into two sub-categories: near-term requirements and long-term requirements. Near-term requirements are those requirements which need to be addressed to deploy a communications system capable of meeting the WPB's data and communication needs for the next 5 years. The ability to access OSC supported applications, such as LEISII, drive these requirements. Long-term requirements are those requirements which will meet the WPB's data and communication needs well into the 21$^{st}$ century.

### 1. Near-term Requirements

Many people performing illegal maritime activity use commercial direction finding equipment to detect and counter Coast Guard communications, which limits the Coast Guard's element of surprise.

Coast Guard surveillance requirements necessitate interagency cooperation to detect illegal activities. Currently target information and positioning data is not shared. Secure communications interoperability with other government agencies is very limited. Record message traffic (i.e. HFDL) is slow and often backlogged.

The CO of the patrol boat has requirements to communicate with its Operational Commander (OPCON), and in some cases high echelons prior to taking certain actions.

In a dynamic law enforcement situation, this communication must be rapid, secure, detailed and accurate. No system exist which meets this need. [Ref. 2, pg. 2-3]

### 2. Long-term Requirements

The Coast Guard has identified numerous long-term communications requirements. G-OLE-1 and G-SCT identifies many of these requirements, but with a different emphasis. G-OLE-1's 1993 analysis provides an overview of what communication requirements are needed to meet the Coast Guard's law enforcement mission needs. [Ref. 2] G-SCT's draft Telecommunications Plan provides a much more extensive and updated analysis of the Coast Guard's overall communications requirements. The draft Telecommunications Plan provides an analysis of the requirements for all the Coast Guard missions and programs.[Ref. 14]

The overall requirements provided by the draft Telecommunications Plan can be broken down into platform and mission specific communications requirements. Table 1 is a consolidated list of high level future requirements by mission area as provided by the Program Managers. The author has eliminated those requirements and mission areas which do not directly apply to an underway, or away from homeport, WPB. For each stated need, the Program Managers have estimated the priority it carries within the mission area. The priorities and corresponding weights assigned are: high priority = 5 (H), medium priority = 3 (M), and low priority = 1 (L). The requirements are further categorized by whether or not the need will carry voice, video, or data (vo, vi, d). The following is a summary of the requirements by mission area:

- **Enforcement of Laws and Treaties/Maritime Law Enforcement (ELT/MLE) and Search and Rescue (SAR)** - A tactical picture during major operations is very important. On-scene units, especially the On-Scene Commander requires the ability to seamlessly and rapidly pass along mission status information and situation reports to oversight personnel (SAR Mission Coordinator; Operational Commander). Users will need the capability to communicate with anyone anytime using a single workstation (for all data needs), or telephone (for all voice communications). "Automatic information" is needed. Data submissions where information is summarized and reported for SAR cases, LE operations, floods, disasters, fuel/provisioning logistics information, etc. should be prepared only once, transmitted, received, logged, and displayed automatically

| Category | Requirements | SAR | ELT/MLE | MEP | CP/DO | RBS | Intel | Log | H | M | L | Total | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| d | Automated Systems/One Time Data Entry | H | H | H | H | H | H | H | 7 | 0 | 0 | 35 | 1 |
| vo,d,vi | CGDN Plus | H | H | H | H | H | H | H | 7 | 0 | 0 | 35 | 1 |
| d | Formal and Informal Message Delivery | H | H | H | H | H | H | H | 7 | 0 | 0 | 35 | 1 |
| vi | Video and Imagery | H | H | H | H | M | H | H | 6 | 1 | 0 | 33 | 4 |
| vo,d,vi | Interoperability | H | H | H | H | H | H | M | 6 | 1 | 0 | 33 | 4 |
| d | Data Security | H | H | H | M | H | H | M | 5 | 2 | 0 | 31 | 6 |
| d | Centralized Data Storage and Access | H | H | H | M | M | M | H | 4 | 3 | 0 | 29 | 7 |
| vo,d,vi | Mobile Communications | H | H | H | H | H | M | L | 5 | 1 | 1 | 29 | 7 |
| d | Automated Chart Updates | H | H | H | H | M | H | L | 5 | 1 | 1 | 29 | 7 |
| d | Remote Access (Dial-in) | M | H | H | M | M | M | H | 3 | 4 | 0 | 27 | 10 |
| vo,d,vi | Provide Navigation Information Services | H | H | H | H | L | H | L | 5 | 0 | 2 | 27 | 10 |
| vo | Short Range Radio Communications | H | H | H | M | H | M | L | 4 | 2 | 1 | 27 | 10 |
| d | Worldwide internal access to Critical CG DB & Applications | M | H | H | M | M | M | M | 2 | 5 | 0 | 25 | 13 |
| vo,d,vi | Satellite Communications | H | H | M | L | L | M | H | 3 | 2 | 2 | 23 | 14 |
| vo,d,vi | Solution to Cutter Antenna Interference Problem | H | H | M | H | L | L | M | 3 | 2 | 2 | 23 | 14 |
| d | Direction Finding Capabilities | H | H | L | H | H | L | L | 4 | 0 | 3 | 23 | 14 |
| d | User Pull | L | M | M | L | L | L | M | 0 | 3 | 4 | 13 | 17 |
| vi,d | Video Teleconferencing | L | L | M | L | L | L | L | 0 | 1 | 6 | 9 | 18 |
| vo,d | Global Dial-Tone | L | L | L | L | L | L | L | 0 | 0 | 7 | 7 | 19 |

| Acronyms | |
|---|---|
| SAR | Search and Rescue |
| MEP | Marine Environmental Protection |
| ELT/MLE | Enforcement of Laws and Treaties/Maritime Law Enforcement |
| CP/DO | Contingency Preparedness/Defense Operations |
| RBS | Recreational Boating Safety |
| Intel | Intelligence |
| Logistics | Logistics (Fleet) |
| d | Data |
| vo | Voice |
| vi | Video and Imagery |

| Statistics | |
|---|---|
| Average | 25.9 |
| Median | 27.0 |
| Mode | 35.0 |
| Std Dev | 8.31 |
| Range | 7-35 |
| Potential Range | 7-35 |

| Scale |
|---|
| High = 5 |
| Medium = 3 |
| Low = 1 |

Table 1. WPB Mission Requirements. After Ref. 14, Deliverable 3, pp. 8-35.

without human intervention. Interoperability with other government agencies is required for large SAR cases and many other major operations. Satellite data links and cellular phones need to be linked together and they need to operate in any environment. On-site case information (ELT, SAR, etc.) may be required in video or imagery format. Imagery is also needed for national intelligence information. G-OCI is interested in obtaining a copy of all non-public affairs imagery, that is collected, for their library in a centralized server located at the Intelligence Coordination Center (ICC). Development of a better satellite solution than INMARSAT is needed, it is currently too expensive. Satellite communication capability is needed between cutters and aircraft. Affordable and reliable communications between operational units and shore facilities is needed. Satellite communications may meet the requirement. A "fusion" site may be needed to reduce equipment requirements (i.e. ANDVT to STU-III phone patches). HFDL is much too slow to meet the growing traffic load requirements. Cutters will also need TCP/IP support. Current systems are too slow. Operations Information System (OIS), currently being developed by the R&D Center, should be fielded to automate and standardize operational reports (i.e. pen based boarding report computer notebook). Cutters need automated chart update capabilities while underway for safety of navigation purposes. There is a requirement to fix antenna interference problems on cutters. The problem is too many antennas, too little space. Cutters must be able to communicate with the majority of commercial and recreational traffic. Cutters must comply with Global Maritime Distress and Safety System (GMDSS) requirements. Direction finding capability for the National Distress System is needed. Funding for cellular and satellite phones is a requirement. [Ref. 14, Deliverable 3, pp. 8-11]

- **Marine Environmental Protection (MEP)** - Interoperability with other government agencies, state and local authorities, and private sector entities, such as those involved in spill clean-ups is required. Cutters need the ability to remotely access publications and directives, along with Marine Safety Information System (MSIS) information using the CG intranet. Imagery capabilities are needed. On-site case information (Marine Environmental Protection (MEP), casualty investigations, etc.) may need to be sent using real-time imagery. VHF-FM communications with clean-up crews, VHF-FM command and control, and cellular phone communications in emergency environments is required. [Ref. 14. Deliverable 3, pp. 7-8]
- **Contingency Preparedness/Defense Operations (CP/DO)** - Affordable and reliable communications with mobile units is required between cutters and aircraft. Updated charts and a solution to the

antenna interference problem must also be addressed. [Ref. 14. Deliverable 3, pg. 34]

- **Recreational Boating Safety (RBS)** - Cutters need to be able to communicate effectively with the public and other government agencies. [Ref. 14. Deliverable 3, pg. 35]
- **Intelligence (Intel)** - Affordable and reliable communications to all Coast Guard mobile units, is needed. TCP/IP connectivity to the ships must be addressed. Interoperability with OGAs is needed. Operational intelligence information must be accessible by the field units. [Ref. 14. Deliverable 3, pg. 35]
- **Fleet Logistics (Log)** - There is a need for efficient and reliable data communications with mobile units. Mobile units need the ability to effectively coordinate logistics support while underway. This includes obtaining critical parts and materials in a timely fashion. Currently, mobile units use INMARSAT, cellular telephone, public telephone system, basic radio communications systems, or other methods available to tap into asynchronous communications to access OSC for updates to systems such as FLS and ARMS/STAR. Access to online publications must be provided. Fast response time to CASREPS drive data delivery. [Ref. 14. Deliverable 3, pg. 35]

The following are descriptions of the requirements assessed in Table 1:

- **Automated Systems/One Time Data Entry** - Data submissions should be reported only once, and the information properly distributed. An example would be the summaries from SAR cases, or other emergencies. A unit shouldn't need to submit a sitrep, boarding report, SARMIS report and SABR for a single case. Automated systems should also be fielded such as automatic position reports to concerned commands.
- **CGDN Plus** - The Coast Guard's future network that will serve as the backbone of its Intranet and support TCP/IP. It must be capable of handling rapidly increasing demands for access to critical data and to meet speed of service requirements. There must be sufficient bandwidth to handle current and future requirements. Bandwidth on demand must be available during surges.
- **Formal and Informal Message Delivery** - All Coast Guard units need some level of formal and informal message delivery capabilities. Cutters have an increasing need for more near real-time data, and when underway to fit more seamlessly into the CGDN.
- **Video and Imagery** - Requirements for video and imagery are increasing across all missions as the technology improves. These include sensor downloads from cutters and aircraft, still picture

transmission, video clips from on scene, national intelligence information, etc.

- **Interoperability** - Fixed and mobile Coast Guard units need the ability to interface and communicate directly with other government agencies. A gateway or "fusion" site may be needed.
- **Data Security** - Limited access, secure and protected systems, and ease of use are required in the same environment. Multi-level security is needed to merge unclassified and classified traffic onto one terminal. This is particularly important if the HFDL replacement is going to be integrated with the shipboard network.
- **Centralized Data Storage and Access** - Access by all units to all data at central locations via a WAN. Access should be available in "real-time" and "near real-time" depending on the user's need.
- **Mobile Communications** - Affordable and reliable communications bandwidth to all Coast Guard Mobile units is needed. The use of state of the art satellite technology may result in improved communications services between shore units, cutters, and aircraft. Satellite services usually provide a faster and more reliable link than traditional methods of radio communications.
- **Automated Chart Updates** - Cutters need automated chart update capabilities while underway for safety of navigation purposes. NAVCEN will be investigating the future requirement to update electronic charts using the installed telecommunications system.
- **Remote Access (Dial-in)** - Remote Access capabilities are needed to allow access for underway units, and personnel.
- **Provide Navigation Information Services** - NAVCEN is tasked with gathering, processing and disseminating timely information to a wide variety of users. There is a requirement to maintain up-to-date technologies in dealing with their client base.
- **Short Range Radio Communications** - The ability to communicate using VHF-FM and UHF is needed to support voice communications with the public, OGA and other Coast Guard units.
- **Worldwide internal access to Critical Coast Guard Databases & Applications** - This is where the bulk of the Coast Guard business takes place. OSC is the access point and maintainer of most Coast Guard systems and must be accessible by outside users.
- **Satellite Communications** - There is a requirement to have satellite communication equipment on board cutters and some aircraft to support data, video and voice communications.
- **Solution to Cutter Antenna Interference Problem** - There is a requirement to fix antenna interference problems on cutters. The problem is too many antennas, too little space. Increased mission

requirements, over the years, have created a much greater demand on cutter communications capabilities than ever before. These demands have brought with them an increased inventory of communications equipment, including a myriad of antennas to handle diverse modes of operation. Close proximity of transmitting and receiving antenna may result in varying levels of interference.

- **Direction Finding Capabilities** - Direction finding capabilities are required for the SAR and ELT missions.
- **User Pull** - Users want to determine the majority of their own data needs. They would like to have the ability to "pull" the information they need, when they need it or when it is convenient, instead of having information "pushed" at them. This requirement needs to be balanced with "smart push" technologies.
- **Video Teleconferencing** - There is a potential need for video teleconferencing during high tempo/high visibility operations.
- **Global Dial-Tone** - Users need the capability to communicate with anyone, anytime, using their workstation (for all data needs) or telephone (for all voice communications).

G-OLE-1 also recommended the following communications requirements in 1993 in support of the Coast Guard's law enforcement mission:

- An installed multi-channel VHF-FM two-way clear/secure voice communications system. In the secure mode, they should be capable of communicating with Coast Guard and other government law enforcement agencies.
- An installed multi-channel UHF two-way clear/secure voice/data communications system. In the secure mode, this system should be able to communicate with CG, OG LEA, and DOD platforms that are working with them.
- An installed real time satellite two-way secure voice and near real-time data/imaging communications system as the primary source for long/short range communications. (Data capability should be compatible with LEISII in the near term, and TCP/IP in the long term). This system should present a low probability of detection/interception by commercial direction finding equipment. The system must have a transmission baud rate of 9600 baud or better for voice/data. It should provide secure and reliable communications anywhere the cutters operate. They should be able to send and receive all forms of CG operational and administrative data.
- An installed multi-channel HF two-way clear/secure voice/data/imaging communications system to be used as a back up if the satellite is taken

away or malfunctions. In the clear mode, the HF system should enable the cutters to communicate with the public or a multinational force.

- The capability to pass data and voice messages simultaneously using satellite or HF equipment.
- The secure interoperability of these installed systems is very important so that these platforms can coordinate multi-agency joint operations.
- These systems should be simple to operate and maintain. They should be designed for use in a harsh marine environment.
- They must be lightweight and compact so they do not exceed the weight constraints of the various platforms.
- The communications system must fit with an overall sensor, communications, command and control architecture designed to collect, process and share sensor and other tactical information among aircraft, cutters and shoreside operations in a timely manner. Equipment must be interoperable across Coast Guard platforms and with DOD. Must be able to process and exchange data real-time or near real-time. Be designed for easy component upgrades. Ensure no need for additional personnel and minimal increase in training requirements. [Ref. 2, pg. 3-5]

## B. THE PATROL BOAT TARGET SYSTEM ARCHITECTURE

### 1. Introduction

The target system architecture shown if Figure 7 provides a general view of what the patrol boat's network architecture should look like in the year 2005. It is designed to meet the current and future needs of the patrol boat by providing flexibility, availability, survivability, and growth. The LAN/WAN architecture is based on well established protocols and standards, and should be supportable through several generations of network devices. The network devices are connected to the LANs with the understanding that the devices and components will be replaced at different times during the lifecycle of the LAN. There should be minimal impact to the other network devices when this occurs.

The least defined area is the ship-to-shore connection. The interface for the ship-to-shore connection must be flexible enough to support both changes in hardware configurations, services and service providers. The shipboard interface must also be robust enough to coordinate both the type of connection to be used and the priority of

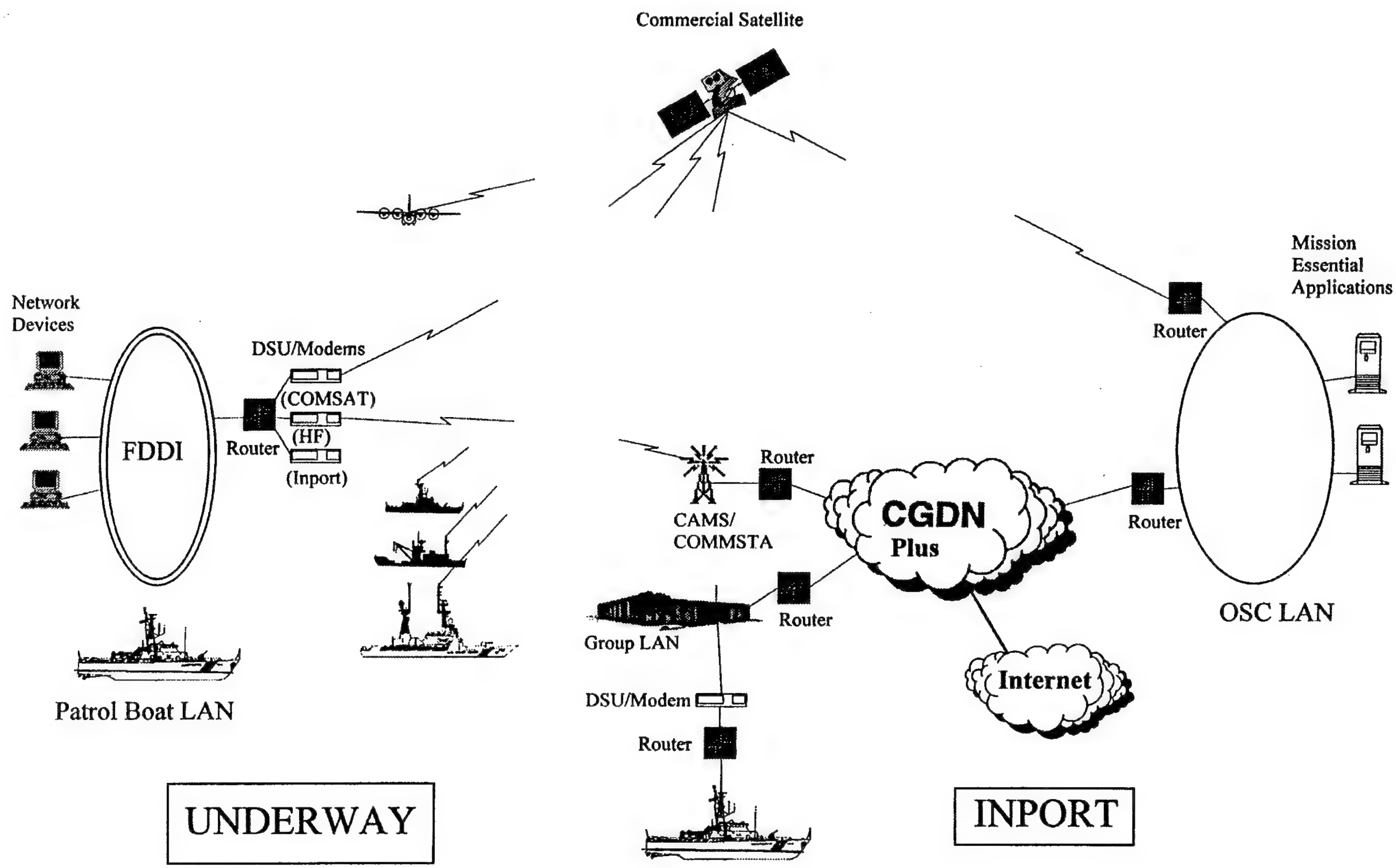


Figure 7. Patrol Boat Target System Architecture.

service to be provided. This area will be the most volatile as the commercial satellite vendors discover ways to capitalize on their investment by adding new services. The subsections that follow provide more detail about the main components of the architecture.

### 2. Cutter LAN

The patrol boat's target system LAN must be designed to support not only the predefined requirements, but also allow for the addition of future needs which have yet to be defined. A dual FDDI ring extending the length of the cutter meets this requirement. Network devices such as computers, printers, navigation devices and communications systems will be connected to the FDDI backbone through either dual or single threaded connections. These devices will be modular in nature so they can be upgraded without effecting the base architecture or other network devices. Every computer terminal will be capable of transmitting and receiving data over the ship-to-shore data connection, provided the user has the proper authority. A router will provide the interface between the patrol boat's LAN and the DSU or modem used to make the ship-to-shore connection. A special purpose computer may also be installed between the router and the DSU/modem to coordinate the routing of traffic based upon priority of service and channel usage.

Computers installed on the bridge and communication room will be the primary systems used to access outside resources like the LEIS II central database and the OPCON's web pages. Within a few years, multiple access protocols will be designed for satellites, allowing the establishment of mobile LANs comprised of cutters, aircraft and shore facilities without requiring large number of point-to-point connections. This will greatly improve the sharing of information and resources among units involved in specific ELT, SAR and MEP operations.

Navigation information from network devices such as the GPS receiver and the AN/SPS-73 radar will be shared among several applications including a patrol boat version of the Shipboard Command and Control System and an electronic charting and navigation system. Extending the LAN the length of the ship will allow for the future expansion of network devices including additional computers and remote sensing and control devices. The remote sensing and control devices can perform such tasks as: video

monitoring of unmanned spaces, computer monitoring of gauges, and computer controlled remote valve alignment and equipment activation.

The patrol boat currently has no established LAN. Most patrol boats have one to three SWS-II computers on board, networked using the SWS-II proprietary master-slave system, for LEIS II and general cutter administration. The 110 ft patrol boats have an additional SWS-II for conducting HFDL communications. It is a standalone secret-high system incapable of sharing information to another onboard computer without violating security restrictions.

The Coast Guard is in the process of replacing the SWS-II with the SWS-III computer. This will give the Coast Guard the flexible computer base needed to operate with the CGDN Plus, which is under development as part of the Coast Guard's draft Telecommunications Plan. [Ref. 14] The SWS-III will also be capable of connecting to today's LAN solutions through the use of an appropriate Network Interface Card. Replacement of all SWS-II computers is not expected to be completed until FY-00 and will cost up to $75M more than the Coast Guard has allocated in the funding base. [Ref. 35, pg. ES-4] Migration is taking place in phases, with the most data intensive units being converted first. Operational units, like the patrol boat, will be the last to transition to SWS-III. [Ref. 35, pg. 1-11] Based on the life cycle of the current SWS-II computer, the SWS-III should be in service beyond the year 2005.

### 3. Ship-to-shore Connection

The patrol boat will rely primarily on high bandwidth satellite service to meet its voice and data communication needs. Private industry will provide the service and infrastructure needed to support connections with high levels of reliability and availability at an affordable price. HF communications will provide a low bandwidth backup system. It will continue to be conducted underway with a COMMSTA or CAMS, which will provide the routing needed to access to the CGDN Plus and other Coast Guard Intranet services. The HF connection is the most likely to dropped in the future as satellite communications meets our needs. Adding a backup communication system to replace HF will be as simple as adding another connection to the router with its associated equipment. As previously addressed, which transmission method is selected should be determined by a special purpose computer on board the cutter. This will be based on the

priority of service and the availability of the channel. Every installed computer will be capable of accessing either transmission medium through the cutter's installed router.

The future ship-to-shore connection must support LANs made up of both mobile and fixed units. The adoption of multiple access protocols will assist in the development of mobile LANs for multi-unit operations, and will provide the means for the shore-based operational commander to issue orders and send information to all units using the smallest amount of bandwidth required. Sharing resources over a virtual network without requiring multiple channels from the satellite to the shore will also be available. This will allow operational units to share information and resources. Aircraft such as the Coast Guard's C-130s will also be able to interact over this network while airborne.

There will be a number of additional uses for the ship-to-shore connection. Besides accessing operational databases like LEIS II, patrol boats will use the connection to submit web-page based position reports, to access directives "on line", to check the sea conditions at a weather buoy during a patrol, to obtain electronic chart updates and to provide innumerable other operation and administrative support functions. The cost of this connection will be manageable. The cost of future satellite communications will drop significantly and will most likely be based on a fixed monthly rate comparable to the unlimited access time charged by today's terrestrial Internet Service Providers. The low cost of unlimited usage will only encourage usage of the system.

The patrol boats are currently restricted in their ability to transmit data while underway. The 110 ft patrol boat has some limited capability with its installed INMARSAT C terminal, however, the 82 ft patrol boat has none. The 110 ft patrol boat is also in the process of receiving a new HF modem which will significantly improve their HF data transmission capability, but until the HFDL computer is connected to the rest of the network, it will not be capable of supporting LEIS II queries, or other unclassified data. A FY99 Resource Change Proposal (RCP) has been submitted to replace the current Harris 3466A HFDL modem with a multimode Rockwell/Collins 3001 modem. The change will provide significant cost savings ($20K per Harris modem vs. $4K per Rockwell/Collins modem) as well as allow the Coast Guard to shift to a more efficient transmission scheme. The Rockwell/Collins modem will support both HFDL and FSK waveforms, providing a relatively painless migration. When the installed base of modems has been upgraded, the Coast Guard Communications Stations will change transmission to the FSK mode. The new transmission mode will allow HF data transmission rates to approach 2400 baud vs. the 300 baud typically observed using

HFDL. The new modem and transmission method will also allow for improved interoperability with the U.S. Navy's HF system.

### 4. Operations Systems Center LAN

The ability to access the OSC will be very important because of its increased role as the central point for the maintenance of essential operational and administrative applications and databases. Underway, the patrol boats will access OSC through a reliable and secure high bandwidth connection established through a privatized satellite service provider. When the connection is established, the cutter will connect to the Coast Guard's Intranet, including access to the OSC LAN, the CGDN Plus, and the authorized portions of the Internet. The applications and databases on the OSC LAN will be optimized to work with a web based browser. LEIS II will also allow for the transfer of images as part of its query response and SABR submission.

The OSC is in the process of increasing the number of applications it is responsible for managing. LEIS II has recently been evaluated and several recommendations to improve the efficiency and speed of replies are being implemented. Shipnet Plus is also in the process of being implemented. While Shipnet Plus does greatly improve the accessibility of OSC managed applications, it is also very inefficient. The one for one assignment of modems wastes the hardware resource. OSC also owns and manages all of the communication hardware, making upgrades and changes to new technologies expensive.

### 5. Inport Connection

The patrol boat's future inport data connection will consist of a point of presence connection to the supporting Group Office through an Internet Service Provider. This connection will provide access to the Coast Guard Intranet and the authorized portions of the Internet through the Group's router. The future connection will be designed to support high bandwidth data transfer, such as that needed for video conferencing. The primary method of navigating the Coast Guard Intranet will be with a web based browser. Widespread use of browser based applications will significantly reduce the time needed to train new users.

Operational web sites should be as small as possible since some units will be restricted to low bandwidth connections (2400 bps). Graphics and backgrounds should

not be used. Differencing software, like IBM's Web Express, will help reduce the amount of data transmitted by 70 to 95%. [Ref. 37, pg. 9] A patrol boat may have a "Cache Server" on board that monitors all browser based activity, so that when a request goes out, it checks the cache first, and then sends a request over the communications channel only when needed. The network administrator can save the cache information from one patrol to the next, and combine it with cache information from inport browsing activities.

The current inport connection to the CGDN has reached its maximum capacity. Some of the bottleneck is associated with the SWS-II computers which only support data rates up to 9600 bps, but it is most commonly associated with the outdated switches maintained at the Coast Guard district offices. The SWS-II computer system is also incompatible with those being used by other government agencies and the general public, making its continued use a source of frustration for the Coast Guard and those people and organizations we communicate with.

## C. SUMMARY

This chapter has reviewed the patrol boat's communication requirements and established a target system architecture. The next step is to investigate current and future technologies. Base on the technologies that meet the requirements, alternatives solutions can be developed and evaluated. The focus of the remainder of this thesis is on the commercial satellite connection between the OSC and the patrol boat. The alternative solutions are developed and evaluated based on the requirements and target system architecture established in this chapter.

# IV. LITERATURE REVIEW

## A. INTRODUCTION TO SATELLITE COMMUNICATIONS

### 1. Orbits

There are four principal types of orbital categories a satellite can be placed in: geostationary earth orbit satellite (GEOS), medium earth orbit satellite (MEOS), low earth orbit satellite (LEOS), and highly elliptical orbit satellite (HEOS). The GEOS are placed in orbit over the equator at an altitude of 35,784 km. They travel in the same direction as the rotation of the Earth and appear to be fixed with respect to a given location on the Earth. Because they are the highest in altitude, the satellites placed in this orbit are generally larger and more expensive to build. Part of the expense is the need to harden the satellites so they can safely transit through the Van Allen radiation belts (1500-5000 and 13,000-20,000 km) as they are placed in orbit. Three GEOS can provide near global coverage, with the areas near the North and South poles excluded. Because of the altitudes associated with GEOS, transmission delays of 1/4 second are experienced in a one-way, single hop transmission. AMSC, DirecPC and INMARSAT-A are examples of commercial GEOS systems.

MEOS orbit the Earth at an altitude of between 8000 and 20,000 km. They only pass through one Van Allen radiation belt, so do not require as extensive hardening as the GEOS. The satellites are placed in circular orbits at an angle to the equator. The benefit of the MEOS over the GEOS is that the user should experience a high average elevation angle, less transmit power is required to communicate with the satellite, and the low altitude will significantly reduce the transmission delays. ICO and Odyssey are examples of proposed MEOS systems.

LEOS orbit the Earth at an altitude of less than 2000 km. They are deployed in circular orbits below the first Van Allen belt and above the Earth's atmosphere to avoid any drag. The lower orbit provides for even higher average elevation angles, less transmit power, and negligible transmission delays. The tradeoff however, is that more satellites are required to provide global coverage (at least 48) and complicated tradeoff schemes between satellites and spot-beams must be provided to ensure a user's signal isn't dropped during a handoff. LEOS have been further subdivided into Mega (or

Broadband), Big and Little-LEOS systems. Orbcomm is an example of a Little-LEOS system, which provides only data transmissions, Globalstar and Iridium are examples of proposed Big-LEOS, and Teledesic is an example of a proposed Broadband-LEOS.

HEOS are deployed in elliptical orbits. They move fastest when closest to the Earth (perigee) and slowest when farthest away (apogee). When nearing their apogee, HEOS behave very similarly to GEOS, except they typically provide better coverage at higher elevation angles (55-60 degrees, which is good for European coverage). Unfortunately, they have a short satellite life, due to periodically passing through the Van Allen radiation belts. [Ref. 1, pg. 133]

### 2. Multiple Access Schemes

Within communications systems, there are three basic techniques for sharing link capacity: frequency-division multiple access (FDMA), time-division multiple access (TDMA), and code-division multiple access (CDMA). The following provides a brief description of the three methods:

> In FDMA systems, each user is assigned a unique center frequency within the operational bandwidth and multiple signals can simultaneously access the satellite amplifier. In a bent-pipe transponder configuration, the satellite translates the entire RF frequency spectrum to form a downlink. To receive the signal, the ground station tunes to the proper band in the downlink spectrum. FDMA represents the simplest way to achieve multiple access, and the required systems technology and hardware are readily available. The key limitation of using FDMA is the need to operate the satellite amplifier at approximately half its maximum output to avoid the generation of unwanted interference.
>
> In TDMA systems, all users transmit on the same frequency and each is assigned the total available bandwidth for a limited amount of time. Unused time regions between slot assignment (guard times) allow for some time uncertainty and act as buffers to reduce interference. TDMA systems segment time into frames, and each frame is further partitioned into assignable time slots. The frame structure repeats so that a fixed TDMA assignment constitutes one or more slots that periodically appear during each frame. Each transmitter sends its data in a burst, timed so as to arrive at the satellite transponder at the assigned time slot. This requires accurate timing and terminal-satellite distance data for all TDMA users. The major advantage of TDMA over FDMA is efficiency, because the

satellite amplifier can be operated at maximum output power since only one carrier arrives at the satellite transponder at any given time.

In CDMA systems, all users transmit simultaneously and at the same frequency, with each being assigned a unique pseudorandom noise code. The data is first phase-modulated by a carrier and then the carrier is biphase-modulated with a pseudorandom noise code that is at a much higher rate than the data traffic. This generates a wide bandwidth, low-energy spread spectrum signal. Each user, in effect, behaves as a low-level interferer to each other user. The received signal is then despread by applying the same code to the received data stream. The maximum number of CDMA users is limited by their aggregate background noise level. CDMA systems suffer from the complexity associated with synchronizing the transmit and receive code and from a limitation in the maximum number of users a given bandwidth can support. [Ref. 29]

Which scheme is used is not as important as the compatibility issues that develop when more than one scheme is used. TDMA and CDMA are more compatible in digital transmission schemes than FDMA, but they still cannot share the same frequency spectrum. With different access methods being used by the various satellite service providers, the FCC has had to work with several providers to ensure the limited amount of spectrum was shared fairly. The FCC's frequency assignment to the Big LEOs is a case in point. Because Iridium will use TDMA and Globalstar and Odyssey will use CDMA, Iridium had to have its own portion of the frequency band assigned while the other two shared the remaining band. TDMA is inherently unable to coexist with CDMA on a single frequency band. While both TDMA and CDMA are being adopted to provide point to point connections in space, neither helps in the development of a "LAN in the sky". [Ref. 29]

## B. CURRENT COAST GUARD MARKET RESEARCH

The Coast Guard is in the process of preparing for a massive restructuring and replacement of its communications systems and architecture. [Ref. 14] The primary reasons for the change are to replace obsolete and high-maintenance systems, to improve compatibility and interoperability with other government agencies, and to implement a network backbone that will meet the Coast Guard's bandwidth requirements well into the next century. There are numerous studies and proposals in the early stages of

development, and Resource Change Proposals (RCP) are being drafted to ensure timely funding of the proposed systems. [Ref. 11]

Third and fourth generation satellites are generating a tremendous amount of excitement within the Coast Guard as better solutions to our mobile data communications requirements are coming online. The small size of our patrol boats along with their extensive communications requirements has made implementation of a relatively inexpensive solution difficult. The following is a brief overview of several studies being conducted to enhance the data communications capability of the patrol boat.

### 1. MILSATCOM

LT Leda Chong, USN MILSATCOM liaison to Coast Guard Telecommunications & Information Systems Command (TISCOM) has been assigned to research the possibility of installing Demand Assigned Multiple Access (DAMA) Military Satellite Communications (MILSATCOM) on board the 110 foot Island Class patrol boat. The purpose of the research is to evaluate MILSATCOM as a means to improve communications between the 110 ft WPB and the assigned "mother ship", typically a 210 ft Medium Endurance Cutter (WMEC). The 110 ft WPB has been increasingly used in support of multi-service and interagency operations which increasingly use MILSATCOM for command and control. Typical of those operations are the long range counter-drug operations in the Caribbean and off the West coast of Mexico, the Alien Migration Interdiction Operations off Haiti and Cuba, and special operations like Operation Restore Democracy in Haiti.

LT Leda Chong has determined that Motorola's LST-5D is the system of choice and could be purchased in conjunction with the currently planned procurement for the 210 ft WHEC. The LST-5D is a light satellite terminal that supports data rates of up to 9600 baud. The priority for usage of the system is: secure voice, tactical data, and support data. The 110 ft WPB would only require access to MILSATCOM when engaged in those types of operations discussed above, which means that the LST-5D would only need to be installed on an "as needed" basis.

Four options are being evaluated: Option one is to maintain the status quo; Option two is to install a LST-5D onboard each of the 49 110 ft WPBs; Option three is to outfit all 110 ft WPBs with racks and mounts, purchase 12 suitcase versions of the LST-5D, and disperse them as needed; Option four is similar to Option three, but to only

purchase six suitcase versions of the LST-5D. The total project cost for each option is as follows:

| Option | Total Project Cost |
| --- | --- |
| Option one | zero |
| Option two | $8,529,000 |
| Option three | $3,375,000 |
| Option four | $2,815,000 |

Table 2. MILSATCOM project costs. [Ref. 10, pp. 3-12.]

Research and refinement of the options continues. Besides cost, the research project is also to address space and weight considerations, which are critical to the 110 ft WPB, as well as maintenance, training and interoperability with installed equipment.

### 2. AMSC Skycell

There are two separate research projects the Coast Guard is conducting on the AMSC Skycell satellite system. LTJG Terry Vogler at TISCOM has installed several high-gain antenna systems on both medium and high endurance cutters to test the data throughput and possible use of AMSC as a lower cost alternative to INMARSAT A. At the same time, LT Gregory Johnson at the Coast Guard Research and Development (R&D) Center is studying the use of a modified AMSC Wavetalk antenna system on board the 110 ft WPB. A test system is installed on board the USCGC MONOMOY in Woods Hole, MA and is being used to access a web server located at the R&D Center. Extensive data is being collected as part of both projects, with weather, throughput and availability being the most critical. A similar system is also being tested for use on the HH-60 Jayhawk helicopter.

### 3. INMARSAT A

A Communications Working Group (CWG) was established at OSC in October 1995 with the primary goal of improving the communications between OSC & underway cutters using the existing communications infrastructure. A secondary goal was to recommend improvements to the data communications infrastructure. While it was

forming, the CWG was assigned to continue with a series of benchmark tests being developed by the OSC Customer Support for use in establishing data to document the efficiency of LEISII queries. A large part of the CWG effort was placed on the benchmark testing.

The original test plan called for the evaluation of several communications configurations on board several cutters. The plan called for testing modems in both asynchronous and virtual dial-in X.25 modes (synchronous), as well as X.25 dial-in over the CGDN. Data was collected regarding the navigation of the cutter, weather conditions and INMARSAT readings. An OSC technician was assigned to collect the data for standardization as well as to limit any additional workload required by the cutter's crew. The data was hoped to provide insight into the problems reported concerning the timeliness of responses, dropouts during communications, and a general lack of connectivity. Table 3 provides a summary of the test results. Only those queries which are typically used by patrol boats have been included:

| Query Type | Asynch STD-A | Virtual X.25 STD-A | X.25 Landline |
|---|---|---|---|
| VSL Name/3 mos. | 17.3 | 2.0 | 2.2 |
| Doc No./3 mos. | 5.7 | 2.0 | 1.3 |
| VSL Name/6 mos. | 9.8 | 1.0 | 2.7 |
| Doc No./6 mos. | 4.5 | 2.0 | 2.0 |
| VSL Name/12 mos. | 9.0 | 17.0 | 1.3 |
| Doc No./12 mos. | 3.6 | 1.8 | 1.2 |
| VSL Name, Doc No./3 mos. | 8.3 | 1.0 | 8.0 |
| Person L,F Name, MI, DOB/3 mos. | 16.1 | 1.9 | 1.0 |
| Lookout Long List - Region | 14.0 | 1.0 | 1.0 |
| SABR Long List. Start/End Geographic Area | 17.0 | 101.0 | 39.0 |

Table 3. Median response time for LEIS II Tactical and List Queries. All times are in minutes. [Ref. 4]

The following observations were made during the benchmark testing:

1. Users did not thoroughly understand what was taking place when an LEISII query was being transmitted. Users mistakenly thought the prompt "Sending Query or Report" indicated the datagram was being transmitted, when in actuality it was only be queued for transmission. Actual transmission of the datagram can only be verified in the application log files.
2. The INMARSAT terminal has gyro but no GPS input for updating position. The position of the cutter is used to provide the satellite with tracking information. When a large distance has been covered without updating the position, the signal strength weakens and a lost signal can result.
3. The ship structure can block the satellite's view of the antenna. A predictable shadow area can be determined for each class of cutters. Severe pitch and roll, as well as land masses can also produce a shadow zone causing the connection to drop.
4. Asynchronous communications is currently a dial-in with no automatic dial-out capability. Because of this, the user must initiate the call to OSC. If the query is processed and the response is ready while the connection is open, the user will receive the response. If the request takes to long to process, the connection may drop out because of a timeout. The typical timeout is set for 90-120 seconds.
5. Testing showed that responses were best for X.25 connections, followed by asynchronous and E-mail. X.25 provided the best response because the datagram could be sent to the cutter as soon as it was ready. The unit did not have to initiate the connection. E-mail was the least desired method because of the delays caused by the additional overhead. However, it does provide for two-way communications.
6. STD-C is very slow to respond, but tactical checks and SABR submissions are possible. While tactical checks are possible, the store & forward e-mail connection does not provide a timely response.
7. Central processing at OSC appears to be functioning well in most cases. Efficiencies can be gained by archiving older data, improving

indexing, and limiting queries to as few search terms as possible (i.e. only search on "Document Number"). [Ref. 4]

The CWG also investigated INMARSAT-A usage by medium and high endurance cutters. INMARSAT-A billings were evaluated on 39 medium and high endurance cutters. Usage was tracked monthly from May 1995 to November 1995. During the months that INMARSAT-A was used, 23% of the usage time was spent accessing LEISII, ranging from 0% to 66% LEISII usage per month. The cutters accessed LEISII an average of 109 minutes per month that INMARSAT-A was used, ranging from 0 to 914.8 minutes per month. [Ref. 4]

### 4. INMARSAT C

The CWG is also studying the use of INMARSAT STD-C to access LEISII and are evaluating the timeliness of the response to queries. When LEISII was originally distributed to the fleet in 1994, three WPBs in the First District were setup to use STD-C for LEISII queries and SABR transmissions. The queries were completed using the STD-C B-mail connection. It was found during the initial testing that the connection did work for SABR submissions, but took too long to get a response from tactical queries. Since then more extensive testing has been conducted by the CWG on the USCGC ROANOKE ISLAND in Homer, AK. Initial results indicate that tactical checks are taking between 5 and 10 minutes. Further testing will take place during the Seventeenth District's patrol boat roundup in May 1997.

### 5. Telecommunications Plan Alternative Analysis

The Coast Guard Communications branch (G-SCT) is in the process of drafting the U.S. Coast Guard Telecommunication Plan. The publication, when promulgated, will provide the Coast Guard with an overall strategy for upgrading its installed communication systems. The draft plan explores future requirements, describes current and future technologies, conducts an alternative analysis, and recommends a desired end state. [Ref. 14]

There are several recommended changes applicable to the patrol boats. Foremost is the shift from HF as a primary communications system to a dual mode system incorporating both satellite and cellular phone and data services. The shift to primary

dependence on satellite data and voice services is not planned until FY-03, well into the life-cycle of the first Big-LEOS, allowing for the technology to prove itself prior to the allocation of any funding. [Ref. 14, Deliverable 10, pp. 23-24] The most significant change to secure communications may be the implementation of CONDOR. CONDOR, under development by Qualcomm, promises STU-III as well as other secure communications capability. If adopted, it is to meet all of our secure communications needs using satellite or cellular phone. [Ref. 14, Deliverable 5, pp. 27-29]

## C. AMSC SKYCELL

AMSC's Skycell provides mobile voice and data communication services to most of the United States through use of a GEO satellite placed in orbit in 1995. AMSC has been authorized to launch up to 3 satellites. Access to Skycell is through a dual mode telephone that first seeks cellular service before switching to the satellite. Data communications is available through a number of terminals, the most promising of which is the Westinghouse Wavetalk antenna system for the patrol boats.

The problem with communications with GEOS is that the user antenna must be locked onto the satellite. This is normally accomplished on land using a VSAT dish antenna. Stabilizing the antenna and maintaining a lock with the satellite adds to the complexity of the design. The Wavetalk system uses a wide elevation angle (15 to 60 degrees) and a rate sensor to track movement and maintain lock on the satellite. The antenna is capable of turning up to 70 degrees per second to maintain lock. Because AMSC support low data rates, up to 4800 bps, a relatively small antenna can be used. The Wavetalk antenna system weighs only about 3 pound and is roughly the size of a bicycle helmet. [Ref. 20]

The AMSC system also allows for "talk groups" to be established. Talk groups may be used for messages or party line applications and show tremendous potential for emergency uses. The groups can be reconfigured over the air without operator intervention when necessary, and with the number of Federal, state and local agencies subscribing to AMSC, true interoperability among emergency response teams may be possible. [Ref. 14, Deliverable 5, pp. 8-9] Table 4 provides an overview of the AMSC system.

| | | |
|---|---|---|
| System | Skycell/MSAT | DirecPC |
| Organization | AMSC, TMI | Hughes |
| Orbital type | GEO | GEO |
| No. of satellites | 2 | 1 |
| Orbit altitude (km) | 35800 | 35800 |
| Satellite lifetime (yrs) | 12 | |
| Coverage | North America, | North America, |
| | Caribbean | Caribbean |
| User link freq (Mhz) | 1646.5-1660.5 (up) | 11700-12200 |
| | 1545-1559 (down) | (down only) |
| Feeder link freq (Mhz) | Ku band | L band |
| | | |
| Repeater type | Bent-pipe | Bent-pipe |
| Access method | FDMA | |
| Max data rate (kbps) | 4.8 | 400 to 2000 |
| Initial/full service | 1995 | 1995 |
| Service costs/min. | $ 1.49 | $180/month |
| Terminals | $ 3,000.00 | $ 7,500.00 |

Table 4. Overview of Skycell and DirecPC.

## D. DIRECPC

Hughes Electronics offers a VSAT networking service called DirecPC, which provides high speed, receive-only access to an intranet or the Internet through the use of the Galaxy IV, a GEO satellite located at 99 West longitude. DirecPC is currently allocated up to 12 Mbps of the Galaxy IV's bandwidth. Since DirecPC is a send only system, a second transmission medium is needed to request information. For the home user, it is typically a modem connected to the public switched telephone network (PSTN). For a cutter, the request would need to be made using either a second satellite system, a data capable radio system, or a cellular phone modem. Hughes believes this asymmetrical type of data exchange is the predominant type taking place, where very little bandwidth is required to request a particular file or web page, but a lot is needed to deliver it, especially when multimedia is involved. Two way high speed data transfer has also been successful using a second VSAT terminal to transmit and the DirecPC terminal to receive.

DirecPC provides three primary services which are accessed through a Windows-based graphical user interface: Multimedia, Package Explorer, and Turbo Internet. The Multimedia service provides a dedicated channel for transmission of full audio/visual broadcasts at 1.2 Mbps. The receive unit is equipped with an MPEG-1 decoder which

permits full motion, full screen video. The system is also capable of providing a number of simultaneous lower bandwidth video broadcasts.

The Package Explorer is a mechanism for the distribution of large data files. The service offers on-demand requests, or the scheduled broadcast of files. Data transmission is conducted at 2 to 3 Mbps.

The final service is the Turbo Internet. It provides the user with fast delivery of information from the Internet (400 kbps). This connection is asymmetrical and requires the user to have a means to request information. [Ref. 22, pp. 1-5]

The 24 inch VSAT terminal will require stabilization to maintain a lock on the satellite. There are several systems available which provide active stabilization on board vessels. The most promising for use on the 110 ft patrol boat is the KVH Active Stabilized Antenna Pedestal (ASAP). It weighs under 35 pounds with the installed radome, and is capable of tracking at 12 degrees per second. [Ref. 3] The most significant obstacles for the patrol boat are the ability to mount the VSAT terminal in a location that is clear of any obstructions and interference, and the ability to add the weight of the antenna mounting and supports without exceeding weight and center of gravity restrictions.

## E. BIG LEOS (IRIDIUM/GLOBALSTAR/ODYSSEY)

The Big LEOS include a number of proposed low and medium earth orbiting satellite systems. The systems are designed to extend the reach of the public switched telephone network to remote and underdeveloped parts of the world. The implications are particularly encouraging to countries lacking the funds to develop a telecommunications infrastructure capable of providing global coverage. The Big LEOS aim to provide that infrastructure. Motorola's Iridium, Loral and Qualcomm's Globalstar and TRW's Odyssey are the most promising designs in terms of financial backing, technical merit, and FCC licensing. [Ref. 29]

The phone service provided by the LEOs is designed to be superior to traditional GEO satellite service. The digital phone service is to provide clear communications without the delays associated with GEO satellite transmissions. Because the satellites are operating in LEO or MEO, user transceivers are significantly smaller than the handsets associated with GEO systems such as AMSC's Skycell.

All three systems are designed to provide seamless interoperability with local cellular phone systems. Each plans on offering a dual mode telephone that automatically switches to the local cellular provider as soon as sufficient signal strength is attained. The dual phone ensures that the user is paying the lowest possible cost for their phone service.

### 1. Iridium

The Iridium system will consist of 66 low earth orbiting satellites (LEOS) designed to do on-board processing and inter-satellite communications. The primary purpose of Iridium is to provide global phone service, and because of its on board processing, the satellite can bypass the ground station to provide direct communications with another subscriber. The design allows the satellites to send messages through each other without having to go through a ground station. When all 66 satellites are in orbit, Iridium will be a digitally switched network in space. Iridium will use Time Division Multiple Access (TDMA) to combine many channels into an aggregate for satellite transmission. TDMA requires exclusive use of the spectrum similar to conventional cellular or radio transmissions.

The on-board processing with intersatellite communications is what makes it different from the competition, which will use traditional bent-pipe repeaters. Critics of the system think that the large number of satellite cross-links makes Iridium unreasonable. Motorola plans to have fifteen to twenty ground gateways to link the satellite system with the terrestrial public switched telephone network. [Ref. 9, pp. 108-114] Table 5 provides a comparison of the Big LEOS.

| System | Globalstar | Iridium | Odyssey |
|---|---|---|---|
| Organization | Loral/Qualcomm | Motorola | TRW |
| Orbital type | LEO | LEO | MEO |
| No. of orbital planes | 8 | 6 | 3 |
| No. of satellites | 48 | 66 | 12 |
| Orbit altitude (km) | 1414 | 780 | 10350 |
| Satellite lifetime (yrs) | 7.5 | 8 | 15 |
| Coverage | Global | Global | Global |
| User link freq (Mhz) | 1610-1621.35 (up) | 1621.35-1626.5 | 1610-1621.35 (up) |
| | 2483.5-2500 (down) | (up and down) | 2483.5-2500 (down) |
| Feeder link freq (Mhz) | 5091-5250 (up) | 29100-29300 (up) | 29200-29500 (up) |
| | 6700-7075 (down) | 19400-19600 (down) | 19400-19700 (down) |
| Repeater type | Bent-pipe | Processing | Bent-pipe |
| Intersatellite links | no | Yes | no |
| Access method | CDMA | TDMA/FDMA | CDMA |
| Max data rate (kbps) | 9.6 | 2.4 | 9.6 |
| Initial/full service | 1998 | 1998 | 2002 |
| Service costs/min. | 0.50 (voice)/1.50 (data) | $ 3.00 | $ 1.00 |
| Terminals | $ 750.00 | $ 2,500.00 | $ 1,000.00 |
| System cost $B | 2 | 3.5 | 1.8 |

Table 5. Overview of Big LEOS.

### 2. Globalstar

Globalstar and Iridium are in direct competition with each other, and are racing to provide satellite telephone service to those areas of the world lacking a telecommunications infrastructure. The Globalstar system will use 48 LEOS with no cross-linking. Each satellite functions as a bent-pipe transponder, receiving signals from phones on the ground and transmitting them back to a ground station gateway. Both the ground station gateway and the received phone signal must be within the satellites 1500 mile wide footprint for communications to work. The gateways will be linked to the local telephone networks. For U.S. coverage, an initial gateway will be established in Texas. Globalstar uses Code Division Multiple Access (CDMA) to enable multiple data channels to be transmitted by satellite. CDMA is a form of spread-spectrum communications that differentiates signals by a spreading code and allow for shared use of the same frequency everywhere. Because of the properties of CDMA, Globalstar and Odyssey will be sharing a portion of the same spectrum. Unlike TDMA systems which can only see one satellite at a time, CDMA handsets have "path diversity" that allows the receivers to combine a number of weak signals in to an intelligible stream. Iridium and other TDMA systems

must compensate for this by using more power; Iridium satellites use 80% more power than Globalstar's and employ antennas nearly twice as large.

Globalstar multiplexes voice channels on the same frequency to take advantage of the relatively high amounts of silence taking place during normal conversations. Because data communications require near dedicated use of a connection, a higher fee will be charged for data transmissions than for voice.

### 3. Odyssey

The Odyssey system will consist of a total of 12 MEOS in three orbital planes. While not technically a LEOS, it is still grouped in that category because of its intended delivery of global satellite telephone service. Odyssey is nearly identical in design and frequency to the ICO system, formerly known as INMARSAT-P. Odyssey is also the least likely of the three Big LEOS to succeed. The estimated date for operation of the satellite system has slipped from 1998, like the other Big LEOs, to a current estimate of 2001. [Ref. 17, pg. 48] The primary reason that Odyssey may not succeed is that the global wireless telephone market may already be saturated by Iridium and Globalstar. If it does get off the ground, the Odyssey system will consist of 12 medium earth orbiting (MEO) satellites in 3 orbital planes. Because the satellites will be higher up, 10350 km, fewer will be required to provide global coverage.

Odyssey will employ CDMA for its modulation scheme and will be a strictly bent-pipe system, like Globalstar. The service will be almost identical to Iridium and Globalstar, with customers being able to use dual mode pocket telephones. Data communications capabilities have been included with each of the Big LEOS. However, there is little improvement over what is currently available from cellular, and GEO satellite providers (i.e. INMARSAT STD A and AMSC).

## F. BROADBAND ON DEMAND

### 1. Teledesic

Teledesic, also referred to as "Internet in the Sky", is the most technically challenging design of the new satellite systems. The "brain child" of Ed Tuck and funded by billionaires Craig McCaw and Bill Gates. Teledesic will be comprised of up to 288 satellites in 12 planes in a sun-synchronous low earth orbit providing broadband

multimedia access anywhere in the world. Schedule to begin operations in 2002, the Teledesic satellites will have onboard processing and communications with eight adjacent satellites to provide for the seamless handoff of signals. The "network" created by this system will be based on Asynchronous Transfer Mode (ATM) switching, similar to that used in the SONET. [Ref. 33]

Each satellite will be capable of supporting 100,000 basic 16 kbps channels. Teledesic plans to use a wide variety of terminals with varying bit rates. The terminals will support bit rates ranging from 16 kbps, plus 2 kbps for signaling, up to 2.048 Mbps (128 basic channels). Terminal antennas will range from 8 cm to 1.8 meters in diameters with power output varying from 0.01 W to 4.7 W. [Ref. 33]

Teledesic will require about 12 times more satellites than any other proposed satellite system. The reason for this is to allow for enough satellites to provide global coverage while maintaining a satellite earth terminal elevation angle of at least 40 degrees. The higher elevation angle will negate some of the interference associated with use of the Ka band for satellite transmissions. A LEO constellation was decided upon to eliminate the latency issues associated with GEO satellites. [Ref. 33]

Originally intended to consist of 840 satellites plus spares, Teledesic scaled back the number of satellites to 288 by increasing the height of the proposed orbit. [Ref. 42, pg 1-4] This change in plans would make the viability of Teledesic more plausible. The most significant issues facing Teledesic is that of cost and launch capacity. Teledesic Corp. is counting on the mass production of its satellites, using standard components, as a means to keep the $9 B system cost from growing. It is also counting on an exponential increase in launch vehicles as commercial launch services are increased by countries such as Russia and China, and as additional companies such as Boeing enter the market. [Ref. 34] Table 6 provides a comparison of the Teledesic and Spaceway systems:

| | | |
|---|---|---|
| System | Teledesic | Spaceway |
| Organization | Teledesic Corp. | Hughes |
| Orbital type | LEO | GEO |
| No. of orbital planes | 12 | N/A |
| No. of satellites | 288 | 9 to 17 |
| Orbit altitude (km) | 700 | 35785 |
| Satellite lifetime (yrs) | 5 | 15 |
| Coverage | Global | Global |
| User link freq (Mhz) | Ka band | 1621.35-1626.5 (up and down) |
| Feeder link freq (Mhz) | Ka band | 29100-29300 (up) 19400-19600 (down) |
| Repeater type | Processing | Processing |
| Intersatellite links | Yes | Yes |
| Access method | TDMA/FDMA | TDMA/FDMA |
| Max data rate (kbps) | 2048 | 1544 |
| Initial/full service | 2002 | 1998 |
| Service costs/min. | $20/month | Unk |

Table 6. Overview of Broadband Systems.

### 2. Galaxy/Spaceway

Spaceway is Hughes Communications, Inc. answer to Teledesic. It plans to offer near global voice, data and two-way video conferencing service. Initial service could start as early as 1999. Spaceway designers have stated that Spaceway will offer all of the capabilities of Teledesic except that it will be a GEO satellite system. Spaceway will be targeted primarily toward computer to computer communications. It will operate in the Ka frequency band and will be designed to bandwidth on demand. Initially the system will consist of 9 geostationary satellites and may expand to 17 satellites as global demand dictates. [Ref. 30]

Communications with the satellite can take place using several different sized terminals. Table 7 provides an overview of the intended data rates supported by the various antennas:

| Terminals | Size | Supported data rates |
|---|---|---|
| Ultra Small Aperture Terminal (USAT) | 66 cm | 384 kbps |
| Very Small Aperture Terminal (VSAT) | 1.2 m | 384 kbps or 1.5 Mbps |
| Broadcast Terminal | 3.5 m | 6 Mbps |
| Downlink Data rates | | 108 Mbps |

Table 7. Spaceway performance summary. After Ref. 16, pg. 110.

Because the systems uses the Ka band, the terminal can also be tuned to receive any one of the broadcast satellite television signals (i.e. DIRECTV, or USSB). The capacity of the system is also affected by the number of simultaneous users. Table 8 provides an overview of the capacity/satellite:

| kbps | 16 | 128 | 384 | 1544 |
|---|---|---|---|---|
| Simultaneous simplex channels | 276,000 | 34,500 | 11,500 | 2880 |

Table 8. Spaceway capacity/satellite. After Ref. 16, pg. 110.

Spaceway will need to overcome several problems to ensure the system works as planned. First, the time delay, or latency, associated with signals transmitted using a GEO satellite may cause intolerable delays. The ½ second delay associated with GEO satellite transmissions will be added to every packet exchanged over a TCP/IP network. Another problem is that Spaceway will require the use of relatively high power handsets or focused beam antennas compared to those required by the Big LEOS.

# V. ALTERNATIVE ANALYSIS USING AHP

## A. INTRODUCTION

This chapter defines the decision criteria, provides a set of alternatives, and through the use of AHP, provides a recommended solution. AHP was chosen over other decision making techniques because of AHP's strength of using a common scale of utility when comparing dissimilar criteria and because of the lack of cost data available on the future satellite systems. AHP is an effective tool for measuring "all important tangible, and intangible, quantitatively measurable, and qualitative factors." [Ref. 38, pg. 1]

Perhaps the most important step is using AHP is the development of the problem hierarchy. This involves breaking the problem down into a various levels of interrelated decision elements. Figure 8 shows the standard form of a problem hierarchy. The top of the hierarchy is the decision objective, followed by one or more levels of attributes contributing to the quality of the decision, and ending with the decision alternatives.

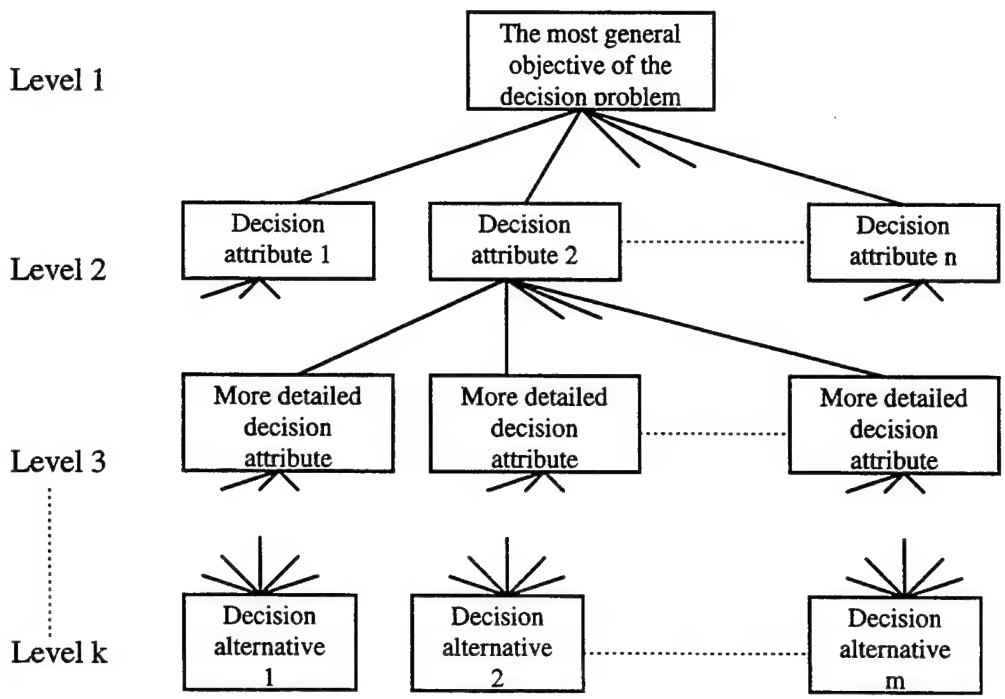


Figure 8. The standard form of decision schema in the Analytic Hierarchy process. From Ref. 40, pg. 97.

The eigenvalue approach to pairwise comparisons provides a way of calibrating a numerical scale. AHP uses pairwise comparisons under the premise that assigning weights to criteria, or performance scores to alternatives is very difficult to do. When making pairwise comparison, the ranking is based upon a 1-9 scale shown in Table 9. Pairwise comparison allows the decision maker to focus on each criteria relevant to the decision. The relative scales used for comparison are also more suitable for the evaluation of intangible properties.

| Intensity of importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective |
| 3 | Weak importance of one over another | Experience and judgment slightly favor one activity over another |
| 5 | Essential or strong importance | Experience and judgment stongly favor one activity over another |
| 7 | Very strong or demon-strated importance | An activity is favored very strongly over another; its dominance demonstrated in practice |
| 9 | Absolute importance | The evidence favoring one activity over another is of the highest possible order of affirmation |
| 2, 4, 6, 8 | Intermediate values between adjacent scale values | When compromise is needed |
| Reciprocals of above nonzero | If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i* | A reasonable assumption |
| Rationals | Ratios arising from the scale | If consistency were to be forced by obtaining *n* numerical values to span the matrix |

Table 9. Scale comparison. From Ref. 38, pg. 54.

While AHP is good tool for decision making, it does have its weakness. The rank order of a solution set has been shown to be subject to "Rank Reversal" upon addition on another alternative. Suppose an AHP solution to a problem provided an alternative ranking of A>B>C>D. Now suppose another alternative is added (E) and additional pairwise comparisons are made for the new alternative. Using AHP, it is possible for the outcome to produce an alternative solution of A>B>E>D>C, where the ranking of alternative C and D are reversed. [Ref. 39, pg. 99]

In structuring the hierarchy of the patrol boat's communications problem, it is important to first structure the objective of the decision problem, then determine the set of attributes (criteria), and finally determine the decision alternatives or selection choices. For the patrol boat, the objective is to connect the underway patrol with OSC's operational databases using the "best communications system". The solution will provide the patrol boat with access to the "shipnet plus" project. The "best communications system" will be determined by weighting the decision criteria based upon the system requirements, and then evaluating the available alternatives based upon the weighted criteria.

## B. CRITERIA

The criteria used to evaluate the possible alternatives are developed by evaluating the requirements discussed in section A of this chapter. Six broad categories of criteria can be easily identified at level 2 which will contribute to making a quality decision, they are: cost, performance, size, compatibility, availability, and security. Each of these criteria can be further broken down into more detailed levels, however for the purposes of this decision objective, level 2 will be sufficient. The following is a description of what is considered within each criteria:

- Cost - This includes all recurring and nonrecurring costs, including installed equipment, spare parts, personnel training and usage fees. The Coast Guard is particularly interested in a system which costs less than INMARSAT-A. For this analysis, the author assumes that the costs associated with maintenance (i.e. spares and preventive maintenance) and personnel would be equal among the alternatives. The primary comparisons were conducted using actual or estimated

equipment costs, and the actual or estimated usage fees. The comparisons are based on a 5 year life-cycle with the anticipated average use being one hour per day for 14 days per month per cutter. This is significantly more usage than the larger cutters made in 1995, they only accessed LEIS II an average of 109 minutes per month. [Ref. 4] The author believes a reliable communications link with timely response to queries will produce a dramatic increase in usage. Since the majority of the systems have yet to be implemented, costs were either estimated or negated (as in the case of Teledesic and Spaceway) during the comparison. Appendix B contains the life cycle cost calculations for the near-term requirements.

- Performance - Performance can be measured in several ways, including data throughput (both sustained and burst), signal delays (latency), and turnaround time of data. In terms of throughput, the near-term solution must be capable of transmitting data a and voice at 2400 bps or better. A long-term solution must provide speeds of 28,800 bps to support low-resolution video delivery; higher if supporting the H.260 standard of P*64kbps, where P can range from 1 to 30. Since SWS-II only supports data speeds of 9600 bps, SWS-III must be fielded to support the higher data rates. This is also where real-time vs. near real-time must be defined. In the near-term, near real-time will mean response to queries received within 10 minutes. In the long-term, delivery of video will demand near isochronous delivery with very little latency (less than 1 second).
- Size - The dimension and weight of the communications system must be suitable for the WPB. Of particular concern is the size of the antenna; it must be suitable for mounting on the mast of 82 and 110 foot WPBs. The 82 foot patrol boat is much more restrictive in terms of the size and weight of the antennas that can be mounted on the mast. Mounting of the antenna anywhere else is unrealistic and would result in large blind spots due to the ship's mast and superstructure blocking the view of the satellite. The 110 ft WPB can support the addition of a small VSAT on its mast.

- Interoperability - Interoperability addresses the ability of the system to work with, or not interfere with, installed equipment, network protocols, and other agency's systems. Interoperability is supported by the principles of commonality, compatibility, standardization, and liaison. [Ref. 43, pp. II-4 to II-5] The recommended system must initially support operations with the current CGDN. It must also support the future CGDN which is being developed as part of the draft Telecommunications plan. The system should work SWS-II computers, and it must work with SWS-III. Ideally the system will support dual mode operation, so the cutter has the option of using the terrestrial cellular system if it results in a cost savings or performance advantage. Having dual mode systems would reduce the number of systems and antennas used on board. Non-interference with other communications systems is important due to the antenna interference problems experienced on cutters in the past. The system should also be interoperable with communications systems used by other government agencies.
- Availability - The system must begin operations within the next two years to meet near-term requirements, and within the next 5 years to meet long-term requirements. The lifetime of the system should be evaluated, as well as the viability of proposed systems. In terms of satellite coverage, a satellite always must be within view of the cutter (20 degree or better elevation angle) within the normal WPB operating area to meet the near-term requirements. Service must be available globally to meet the long-term requirements. The system availability should be compared with the commercial standard of about 99.7%. The location of the antenna on the cutter and the maintenance of the system must be considered. Operational Availability (Ao) is defined as the total time minus the down time, divided by the total time.

  Ao[system]=Ao[component1]*Ao[component2]*...Ao[componentN]

  Ao[system] = 0.999*0.997*0.9999*0.9995*0.999

  Ao[system] = 0.994 or 99.4% (about 4 hours per month down time)

To improve availability through redundancy, compute the following: Subtract Ao[component (or system)] from 1. This represents the probability that the component will fail. Multiply the probability of failure for each part together and you get the probability that both components (or systems) will fail at the same time.

Suppose you have two completely redundant systems with an availability of 99.7%. In this case, you subtract the availability of each system from 1 to get the percentage of time the system will not be available (1-.997 = .003). Multiply the time not available for each redundant system to get the percentage of time all systems will be down at the same time (0.003 * 0.003 = 0.000009). This results in the availability of the system (99.9991%, or both systems will be down at the same time 40 seconds per month on average). [Ref. 36]

- Security - Security is meant to include the level and type of encryption technology used, as well as the security of the cutter from detection through the use of direction finding equipment. The system must be capable of providing at least DES level link security using either end-to-end hardware encoding (like the currently used X5000), or application layer messaging security through software encoding using a product like Nortel's Entrust. [Ref. 41] There is currently no encryption used during asynchronous communications with OSC.

## C. ALTERNATIVES

The first step in evaluating alternatives, is to produce a broad list of alternatives, against which screening criteria are applied to filter out infeasible candidates. Care must be taken to not select screening criteria which may cause you do not evaluate the "best" alternative because it failed an arbitrarily assigned filter, but would have excelled in all other criteria.

The following is a complete list of possible alternatives prior to filtering. For all but the first alternative, it is assumed the RCP for the HF modem replacement is approved for 110 ft WPB. The 82 ft WPB's HF radio is only capable of voice communications.

1. Maintain Status Quo. 82's will have no data capability. 110's will have limited coverage using INMARSAT-C.
2. AMSC using Wavetalk antenna.
3. DirecPC with AMSC and Wavetalk antenna.
4. Iridium.
5. Globalstar.
6. Odyssey.
7. Teledesic.
8. Spaceway.

A minimum set of constraint criteria is applied to eliminate the unfeasible alternatives for a near-term solution. The minimum set of constraint criteria consists of:

- Capable of transmitting data and voice at 2400 bps or better.
- Antenna suitable for mounting on the mast of 82 and 110 foot WPBs.
- Support transmission for X.25 and TCP/IP protocols.
- Operational within the next two years.
- Coverage must be continuous within the normal WPB operating area.

After applying the constraint criteria, the following alternatives are left for consideration:

- AMSC using the Wavetalk antenna.
- Iridium.
- Globalstar.

The requirement that the system provide at least 2400 bps coverage eliminated the first alternative. The requirement that the antenna be mountable on board both the 82 and 110 foot patrol boat eliminated alternatives three and eight. The requirement that the system be operational within the next two years eliminated the sixth and seventh alternatives. The three alternatives remaining meet all screening criteria and will be evaluted using AHP to determine the best solution to the near-term requirements.

The same screening process can be applied to the alternatives to determine a long-term solution. However, the screening requirements will change to include the need for global coverage and higher bandwidth to support video. The following constraint criteria are applied:

- Capable of transmitting data a and voice at 28,000 bps or better.
- Antenna suitable for mounting on the mast of 110 foot and the 82 foot WPB replacement.
- Support transmission for TCP/IP protocols.
- Coverage must be continuous worldwide.

Applying the screening to the current list of alternatives results in only two suitable alternatives: Teledesic, and Spaceway. The higher bandwidth and global coverage requirement eliminates all other currently known alternatives. Evaluation of alternatives for the long-term solution should be completed closer to the actual implementation of the system. This allows the decision maker to consider new alternatives, and provides the decision maker with more current cost and performance data on the proposed alternatives; especially after the satellite systems are operational.

## D. AHP

The decision criteria and alternatives are evaluated using the Analytic Hierarchy Process to Multiple Criteria Decision Making. The detailed matrix for both near and long-term solutions are contained in Appendix A. The evaluation of the solutions are provided in the following subsections.

### 1. Near-term

The hierarchical decision schema for the near-term communications requirement is shown in Figure 9.

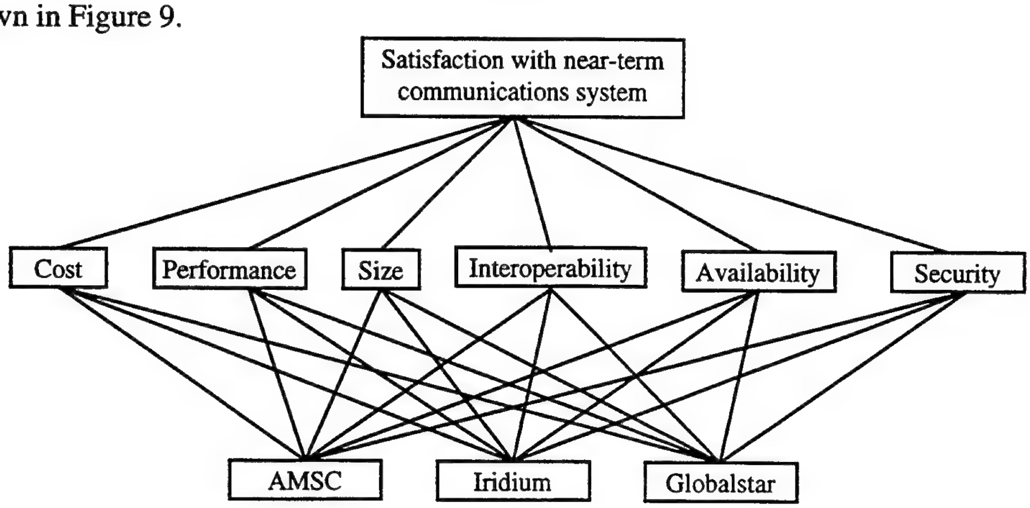


Figure 9. Near-term hierarchical decision schema.

Table 10 shows a pairwise comparison of all six criteria including the associated priority vector, eigenvalue (EV), consistency index (CI) and consistency ratio (CR) for the near-term requirements. A consistency ratio of 0.1 or less is considered acceptable.

| | cost | perf. | size | inter. | avail. | security | Priority Vector |
|---|---|---|---|---|---|---|---|
| cost | 1 | 4 | 7 | 0.333 | 0.333 | 7 | 19.4 |
| perf. | 0.250 | 1 | 3 | 0.500 | 0.167 | 3 | 8.8 |
| size | 0.143 | 0.3333 | 1 | 0.250 | 0.143 | 1 | 4.0 |
| inter. | 3 | 2 | 4 | 1 | 0.333 | 3 | 19.7 |
| avail. | 3 | 6 | 7 | 3 | 1 | 8 | 44.1 |
| security | 0.143 | 0.3333 | 1 | 0.333 | 0.125 | 1 | 4.1 |
| | | | | | | sum= | 100.0 |
| | | | | EV= | 6.4894 | | |
| | | | | CI= | 0.0979 | | |
| | | | | CR= | 0.0789 | | |

Table 10. Pairwise comparison of near-term decision criteria.

The priority vectors show the author's weighting of the decision criteria with the following order of priority: availability (44.1%), interoperability (19.7%), cost (19.4%), performance (8.8%), security (4.1%) and size (4.0%). The availability of the system is clearly the dominant decision criteria and provides the most weight to the decision. The size and performance criteria would have received a higher priority vector if constraint criteria were not in place.

Table 11 shows the solution matrix. The priority vectors (or weighting) from the pairwise comparison for each decision criteria are shown along with the final worth of the alternatives based upon the weighting of the decision criteria.

| | cost | perf. | size | inter. | avail. | security | |
|---|---|---|---|---|---|---|---|
| Alt\Weight | 19.4 | 8.8 | 4.0 | 19.7 | 44.1 | 4.1 | Worth |
| AMSC | 23.0 | 30.9 | 11.1 | 50.0 | 13.6 | 50.0 | 25.5 |
| Iridium | 12.2 | 10.9 | 44.4 | 25.0 | 62.5 | 25.0 | 38.6 |
| Globalstar | 64.8 | 58.2 | 44.4 | 25.0 | 23.8 | 25.0 | 35.9 |
| | | | | | | SUM= | 100 |

Table 11. Solution matrix to near-term requirements.

Based on AHP, Iridium is the preferred alternative with a value of 38.6%. It should be noted that Iridium was superior to the other two solutions only the availability criteria, due to its truly global coverage and intersatellite communications. If only cost

and performance were considered, Globalstar would have been the clear winner. AMSC is strongest in compatibility and security due to its ability to support "talk groups" and recent efforts to develop STU-III compatible systems.

### 2. Long-term

The hierarchical decision schema for the long-term communications requirement is shown in Figure 10.

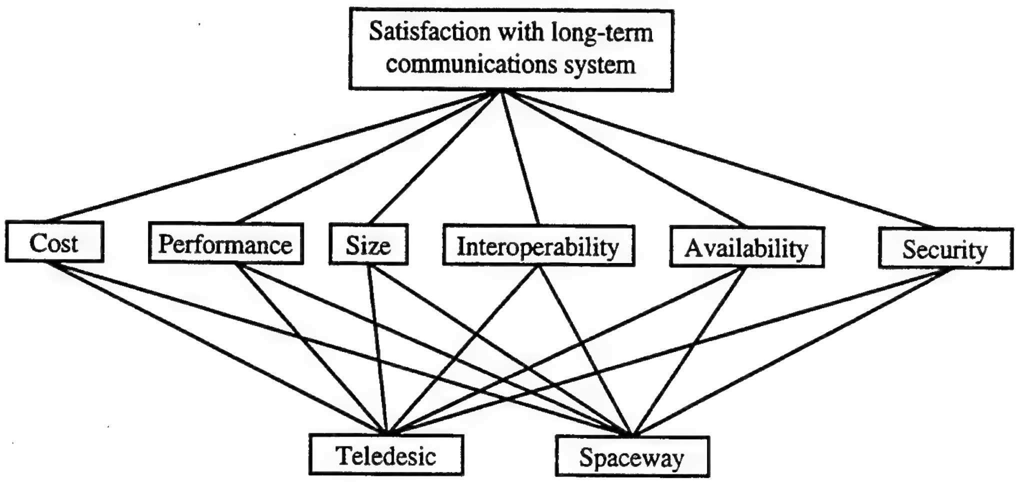


Figure 10. Long-term hierarchical decision schema.

Table 12 shows a pairwise comparison for the long-term requirements.

| | cost | perf. | size | inter. | avail. | security | Priority Vector |
|---|---|---|---|---|---|---|---|
| cost | 1 | 0.500 | 7 | 0.333 | 0.125 | 4 | 10.5 |
| perf. | 2 | 1 | 5 | 4 | 0.500 | 5 | 24.8 |
| size | 0.143 | 0.200 | 1 | 0.333 | 0.143 | 1 | 3.8 |
| inter. | 3 | 0.250 | 3 | 1 | 0.333 | 4 | 13.8 |
| avail. | 8 | 2 | 7 | 3 | 1 | 8 | 43.0 |
| security | 0.250 | 0.200 | 1 | 0.250 | 0.125 | 1 | 3.9 |
| | | | | | | sum= | 100.0 |
| | | | | EV= | 6.5867 | | |
| | | | | CI= | 0.1173 | | |
| | | | | CR= | 0.0946 | | |

Table 12. Pairwise comparison of long-term decision criteria.

The priority vectors show the author's weighting of the decision criteria with the following order of priority: availability (43.0%), performance (24.8%), interoperability (13.8%), cost (10.5%), security (3.9%) and size (3.8%). The availability of the system is still the dominant decision criteria, however, performance will play a much more important role in the future.

Table 13 shows the solution matrix. The priority vectors (or weighting) from the pairwise comparison for each decision criteria are shown along with the final value of the alternatives based upon the weighting of the decision criteria.

| | cost | perf. | size | inter. | avail. | security | |
|---|---|---|---|---|---|---|---|
| Alt\Weight | 10.5 | 24.8 | 3.8 | 13.9 | 43.0 | 3.9 | Worth |
| Teledesic | 50.0 | 66.7 | 80.0 | 66.7 | 33.3 | 50.0 | 50.4 |
| Spaceway | 50.0 | 33.3 | 20.0 | 33.3 | 66.7 | 50.0 | 49.6 |
| | | | | | | SUM= | 100 |

Table 13. Solution matrix to long-term requirements.

In this case there is no clear solution. It is important to note the importance of reevaluating the systems as more substantial information is gained. Neither system is operational, and there will surely be many changes to the planned systems before they are launched. Additional information on usage fees and antenna design (particularly for Teledesic) may provide the information needed to select the best alternative for the Coast Guard.

## E. BENEFITS

There are many benefits to providing the patrol boats with timely and reliable access to the LEISII database, the most important of which is the improved safety of the boarding teams. However, cost savings is not applicable. The patrol boats do not have an installed system that is used for data communications, so the costs associated with adopting a data communications system like Iridium (or Teledesic, or Spaceway) would need to be added into the budget as a new line item. The benefits outweigh the costs. Access to the database provides:

- Increased use of a valuable Coast Guard resource which is currently underutilized.
- Faster processing of operations. Quick response to queries increases the value of the information.

- Improved customer service. The patrol boats would have access to the MSIS/VDOC information and would only have to verify the information, instead of rewrite it. This saves time on the boarding. The patrol boat would also know if and when the boat was last boarded by the Coast Guard, rather than trusting the word of the operator, or looking foolish sending a boarding team to look at the operators copy of report to verify it.
- Improved decision process by providing better information faster. This is a very important aspect for the Commanding Officer and the boarding team. The CO can make informed boarding decisions based upon timely information, and the boarding team can be better prepared for the boarding rather than going in ignorant of their current situation.
- Positive effects on other classes of resources. By adopting the recommended systems, the patrol boat has a means of effectively communicating with any Coast Guard unit at any time. The chances of the patrol boat being in an area with no communications is virtually eliminated. This allows the operational commander to more effectively task units. A direct link with a unit is easily accomplished. By having a data communications system in place, the unit can also conduct more administrative business underway, such as ordering critical parts underway using STAR/ARMS, or checking a crewmember's PMIS records.

## F. SUMMARY

The connectivity requirements for the patrol boats are in the process of changing, particularly as new satellite technology is promising to make worldwide broadband mobile access a reality. For the Coast Guard, the initial effort must be in providing the patrol boats with the equipment needed to access the CGDN (and LEIS II) while underway in its normal operating area. Iridium is the best solution to the patrol boats near-term needs.

Long-term, the patrol boats must be capable of transmitting video and imagery, as well as voice and data. These high bandwidth needs will require a "bandwidth on demand" solution. As Spaceway and Teledesic are fielded and tested, they, along with

any other global broadband system, should be reevaluated for installation not only on the patrol boats, but on all cutters.

AHP is a very good mathematical approach to multiple criteria decision making. While this thesis only considered six broadly classified decision criteria, with the author as the sole decision maker, AHP can be used to evaluate multiple levels of decision criteria with a group of decision makers. A well designed and knowledgeable group can ensure that all biases are eliminated from the decision process and that each Program Manager's requirements are addressed. The decision group should include representatives from both the Program Manager's office and the patrol boat fleet. The decision matrix developed for this analysis is constructed from the authors point of view, which is based on four years service on 110 foot patrol boats.

# VI. CONCLUSIONS, AND RECOMMENDATIONS

## A. CONCLUSION

The Coast Guard must provide the patrol boats with the equipment necessary to access the CGDN and LEIS II while underway. For the near-term (within the next 5 to 7 years) Iridium is the best solution to the current requirements. Iridium combines voice and low bandwidth data capabilities with global coverage to provide a system capable of giving the patrol boats access to both the CGDN and the LEIS II central database while underway. With this system, the patrol boats will be able to conduct near real-time tactical queries on the LEIS II central database, and conduct business over the CGDN if required.

Long-term, the patrol boats must be capable of transmitting video and imagery, as well as voice and data. These requirements can only be met with a "bandwidth on demand" solution. Spaceway and Teledesic are two systems which show tremendous promise as solution to the patrol boat's long-term needs. Since their design has yet to be finalized, they, along with other global broadband systems should be reevaluated for installation on the patrol boats.

## B. RECOMMENDATIONS

The implementation of a satisfactory communications system for the Coast Guard patrol boat needs to be completed in phases. The first phase must be to give the patrol boats the ability to access the operational databases at the OSC. The 82 foot patrol boats currently have no means of connecting to the LEIS II central database, and the 110 foot patrol boat's INMARSAT C connection is too slow and intermittent to be considered viable. Within the next two years every patrol boat should have an Iridium system installed that will allow for 2400 bps data connectivity with the OSC using a virtual X.25 connection. The Iridium system should be equipped with a dual mode voice system which will integrate seamlessly with the terrestrial cellular phone system; eliminating the need for a separate cellular phone. The dual mode designed phone will replace the currently unauthorized cellular phones found on board most patrol boats with a supported, standardized system. The important aspect of the first phase is that it is not a

satisfactory long-term solution. It is strictly a near-term solution, that must be dropped in favor of a high-bandwidth system within the next five to seven years.

The long-term solution should be implemented as soon as the network infrastructure is in place to support it. Too many future needs require a high bandwidth solution, including interaction on the planned Coast Guard intranet. Considerations for the design of the follow-on patrol boat to the 82 foot WPB must address structural support of the larger terminals. The Teledesic and Spaceway systems must also be reevaluated as updated cost, design and capability information becomes available. "Broadband on demand" systems such as these will be the ones that will meet the patrol boat's communications needs well into the next century.

# APPENDIX A. ANALYTIC HIERARCHY MATRIX CALCULATIONS

This appendix contains the complete solution matrices for both the near and long-term requirements.

Near-term requirements calculations:

| Criteria | |
|---|---|
| 1 | Cost |
| 2 | Performance |
| 3 | Size |
| 4 | Interoperability |
| 5 | Availability |
| 6 | Security |

| Alternatives | |
|---|---|
| A | AMSC |
| B | Iridium |
| C | Globalstar |

EV= Eigenvalue
CI= Consistency Index
CR= Consistency Ratio
PV= Priority Vector

Table of pairwise comparisons for criteria:

| | 1 | 2 | 3 | 4 | 5 | 6 | Priority Vector |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 4 | 7 | 0.333 | 0.333 | 7 | 0.194 |
| 2 | 0.250 | 1 | 3 | 0.500 | 0.167 | 3 | 0.088 |
| 3 | 0.143 | 0.3333 | 1 | 0.250 | 0.143 | 1 | 0.040 |
| 4 | 3 | 2 | 4 | 1 | 0.333 | 3 | 0.197 |
| 5 | 3 | 6 | 7 | 3 | 1 | 8 | 0.441 |
| 6 | 0.143 | 0.3333 | 1 | 0.333 | 0.125 | 1 | 0.041 |
| | | | | | | Sum= | 1.000 |

| | |
|---|---|
| EV= | 6.4894 |
| CI= | 0.0979 |
| CR= | 0.0789 |

A consistency ratio of .1 or less is considered acceptable.

| E | nth root | normal |
|---|---|---|
| 21.778 | 1.6711 | 0.1937 |
| 0.1875 | 0.7565 | 0.0877 |
| 0.0017 | 0.3455 | 0.04 |
| 24 | 1.6984 | 0.1968 |
| 3024 | 3.8027 | 0.4407 |
| 0.002 | 0.3545 | 0.0411 |
| Sum= | 8.6287 | 1 |

| Y | Y/PV |
|---|---|
| 1.3247 | 6.8403 |
| 0.5513 | 6.2881 |
| 0.2502 | 6.2483 |
| 1.3835 | 7.0289 |
| 2.7472 | 6.2336 |
| 0.2587 | 6.2975 |
| Sum= | 38.937 |
| EV= | 6.4894 |

Solution matrix

| | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| Alt\Weight | 19.4% | 8.8% | 4.0% | 19.7% | 44.1% | 4.1% | Worth/Value |
| A | 23.0% | 30.9% | 11.1% | 50.0% | 13.6% | 50.0% | 25.5% |
| B | 12.2% | 10.9% | 44.4% | 25.0% | 62.5% | 25.0% | 38.6% |
| C | 64.8% | 58.2% | 44.4% | 25.0% | 23.8% | 25.0% | 35.9% |
| | | | | | | Sum= | 100% |

Cost

| | A | B | C | PV |
|---|---|---|---|---|
| A | 1 | 2 | 0.33 | 23% |
| B | 0.5 | 1 | 0.20 | 12% |
| C | 3 | 5 | 1 | 65% |
| | | | Sum= | 100% |
| | EV= | 3.0037 | | |

| E | nth root | normal | Y | Y/PV |
|---|---|---|---|---|
| 0.6667 | 0.8736 | 0.2297 | 0.6898 | 3.0037 |
| 0.1 | 0.4642 | 0.122 | 0.3665 | 3.0037 |
| 15 | 2.4662 | 0.6483 | 1.9474 | 3.0037 |
| Sum= | 3.804 | 1 | | 9.0111 |
| | | | EV= | 3.0037 |

Performance

| | A | B | C | PV |
|---|---|---|---|---|
| A | 1 | 3 | 0.50 | 31% |
| B | 0.3333 | 1 | 0.20 | 11% |
| C | 2 | 5 | 1 | 58% |
| | | | SUM= | 100% |
| | EV= | 3.0037 | | |

| E | nth root | normal | Y | Y/PV |
|---|---|---|---|---|
| 1.5 | 1.1447 | 0.309 | 0.9281 | 3.0037 |
| 0.0667 | 0.4055 | 0.1095 | 0.3288 | 3.0037 |
| 10 | 2.1544 | 0.5816 | 1.7468 | 3.0037 |
| Sum= | 3.7046 | 1 | | 9.0111 |
| | | | EV= | 3.0037 |

Size

| | A | B | C | PV |
|---|---|---|---|---|
| A | 1 | 0.25 | 0.25 | 11% |
| B | 4 | 1 | 1 | 44% |
| C | 4 | 1 | 1 | 44% |
| | | | Sum= | 100% |
| | EV= | 3.00 | | |

| E | nth root | normal | Y | Y/PV |
|---|---|---|---|---|
| 0.0625 | 0.3969 | 0.1111 | 0.3333 | 3 |
| 4 | 1.5874 | 0.4444 | 1.3333 | 3 |
| 4 | 1.5874 | 0.4444 | 1.3333 | 3 |
| Sum= | 3.5717 | 1 | | 9 |
| | | | EV= | 3 |

Interoperability

| | A | B | C | PV |
|---|---|---|---|---|
| A | 1 | 2 | 2 | 50% |
| B | 0.5 | 1 | 1 | 25% |
| C | 0.5 | 1 | 1 | 25% |
| | | | Sum= | 100% |
| | EV= | 3 | | |

| E | nth root | normal | Y | Y/PV |
|---|---|---|---|---|
| 4 | 1.5874 | 0.5 | 1.5 | 3 |
| 0.5 | 0.7937 | 0.25 | 0.75 | 3 |
| 0.5 | 0.7937 | 0.25 | 0.75 | 3 |
| Sum= | 3.1748 | 1 | | 9 |
| | | | EV= | 3 |

Availability

| | A | B | C | PV |
|---|---|---|---|---|
| A | 1 | 0.25 | 0.50 | 14% |
| B | 4 | 1 | 3 | 63% |
| C | 2 | 0.33 | 1 | 24% |
| | | | Sum= | 100% |
| | EV= | 3.0183 | | |

| E | nth root | normal | Y | Y/PV |
|---|---|---|---|---|
| 0.125 | 0.5 | 0.1365 | 0.412 | 3.0183 |
| 12 | 2.2894 | 0.625 | 1.8865 | 3.0183 |
| 0.6667 | 0.8736 | 0.2385 | 0.7198 | 3.0183 |
| Sum= | 3.663 | 1 | | 9.0549 |
| | | | EV= | 3.0183 |

Security

| | A | B | C | PV |
|---|---|---|---|---|
| A | 1 | 2 | 2 | 50% |
| B | 0.5 | 1 | 1 | 25% |
| C | 0.5 | 1 | 1 | 25% |
| | | | Sum= | 100% |
| | EV= | 3 | | |

| E | nth root | normal | Y | Y/PV |
|---|---|---|---|---|
| 4 | 1.5874 | 0.5 | 1.5 | 3 |
| 0.5 | 0.7937 | 0.25 | 0.75 | 3 |
| 0.5 | 0.7937 | 0.25 | 0.75 | 3 |
| Sum= | 3.1748 | 1 | | 9 |
| | | | EV= | 3 |

Long-term requirements calculations:

| Criteria | |
|---|---|
| 1 | Cost |
| 2 | Performance |
| 3 | Size |
| 4 | Interoperability |
| 5 | Availability |
| 6 | Security |

| Alternatives | |
|---|---|
| A | Teledesic |
| B | Spaceway |

Table of pairwise comparisons for criteria:

| | 1 | 2 | 3 | 4 | 5 | 6 | Priority Vector |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0.500 | 7 | 0.333 | 0.125 | 4 | 0.105 |
| 2 | 2 | 1 | 5 | 4 | 0.500 | 5 | 0.248 |
| 3 | 0.143 | 0.200 | 1 | 0.333 | 0.143 | 1 | 0.038 |
| 4 | 3 | 0.250 | 3 | 1 | 0.333 | 4 | 0.138 |
| 5 | 8 | 2 | 7 | 3 | 1 | 8 | 0.430 |
| 6 | 0.250 | 0.200 | 1 | 0.250 | 0.125 | 1 | 0.039 |
| | | | | | | SUM= | 1.000 |

| | |
|---|---|
| EV= | 6.5867 |
| CI= | 0.1173 |
| CR= | 0.0946 |

| E | nth root | normal |
|---|---|---|
| 0.5833 | 0.9141 | 0.1054 |
| 100 | 2.1544 | 0.2484 |
| 0.0014 | 0.3329 | 0.0384 |
| 3 | 1.2009 | 0.1385 |
| 2688 | 3.7288 | 0.43 |
| 0.0016 | 0.3406 | 0.0393 |
| Sum= | 8.6718 | 1 |

| Y | Y/PV |
|---|---|
| 0.7554 | 7.1661 |
| 1.6165 | 6.5068 |
| 0.25 | 6.5129 |
| 0.9324 | 6.733 |
| 2.7686 | 6.4386 |
| 0.2421 | 6.1626 |
| Sum= | 39.52 |
| EV= | 6.5867 |

Solution matrix

| | 1 | 2 | 3 | 4 | 5 | 6 | |
|---|---|---|---|---|---|---|---|
| Alt\Weight | 0.1054 | 0.2484 | 0.0384 | 0.1385 | 0.4300 | 0.0393 | Worth |
| A | 0.5000 | 0.6667 | 0.8000 | 0.6667 | 0.3333 | 0.5000 | 0.504 |
| B | 0.5000 | 0.3333 | 0.2000 | 0.3333 | 0.6667 | 0.5000 | 0.496 |
| | | | | | | Sum= | 1.000 |

Cost

| | A | B | PV |
|---|---|---|---|
| A | 1 | 1 | 50% |
| B | 1 | 1 | 50% |
| | | Sum= | 100% |
| EV= | 2 | | |

| E | nth root | normal | Y | Y/PV |
|---|---|---|---|---|
| 1 | 1 | 0.5 | 1 | 2 |
| 1 | 1 | 0.5 | 1 | 2 |
| Sum= | 2 | 1 | | 4 |
| | | | EV= | 2 |

Performance

| | A | B | PV |
|---|---|---|---|
| A | 1 | 2 | 67% |
| B | 0.5 | 1 | 33% |
| | | Sum= | 100% |
| EV= | 2 | | |

| E | nth root | normal | Y | Y/PV |
|---|---|---|---|---|
| 2 | 1.4142 | 0.6667 | 1.3333 | 2 |
| 0.5 | 0.7071 | 0.3333 | 0.6667 | 2 |
| Sum= | 2.1213 | 1 | | 4 |
| | | | EV= | 2 |

Size

| | A | B | PV |
|---|---|---|---|
| A | 1 | 4 | 80% |
| B | 0.25 | 1 | 20% |
| | | Sum= | 100% |
| EV= | 2 | | |

| E | nth root | normal | Y | Y/PV |
|---|---|---|---|---|
| 4 | 2 | 0.8 | 1.6 | 2 |
| 0.25 | 0.5 | 0.2 | 0.4 | 2 |
| Sum= | 2.5 | 1 | | 4 |
| | | | EV= | 2 |

Interoperability

| | A | B | PV |
|---|---|---|---|
| A | 1 | 2 | 67% |
| B | 0.5 | 1 | 33% |
| | | Sum= | 100% |
| EV= | 2 | | |

| E | nth root | normal | Y | Y/PV |
|---|---|---|---|---|
| 2 | 1.4142 | 0.6667 | 1.3333 | 2 |
| 0.5 | 0.7071 | 0.3333 | 0.6667 | 2 |
| Sum= | 2.1213 | 1 | | 4 |
| | | | EV= | 2 |

Availability

| | A | B | PV |
|---|---|---|---|
| A | 1 | 0.5 | 33% |
| B | 2 | 1 | 67% |
| | | Sum= | 100% |
| EV= | 2 | | |

| E | nth root | normal | Y | Y/PV |
|---|---|---|---|---|
| 0.5 | 0.7071 | 0.3333 | 0.6667 | 2 |
| 2 | 1.4142 | 0.6667 | 1.3333 | 2 |
| Sum= | 2.1213 | 1 | | 4 |
| | | | EV= | 2 |

Security

| | A | B | PV |
|---|---|---|---|
| A | 1 | 1 | 50% |
| B | 1 | 1 | 50% |
| | | Sum= | 100% |
| EV= | 2 | | |

| E | nth root | normal | Y | Y/PV |
|---|---|---|---|---|
| 1 | 1 | 0.5 | 1 | 2 |
| 1 | 1 | 0.5 | 1 | 2 |
| Sum= | 2 | 1 | | 4 |
| | | | EV= | 2 |

# APPENDIX B. COST ANALYSIS

## A. COST CATEGORIES

### 1. ACQUISITION COSTS

The first cost category to be evaluated is the acquisition costs. These are the hardware costs associated with installing the new system. For the satellite systems, these costs include the antenna system and any structural changes needed on the cutter to support the antenna, and the cost of the initial spare parts inventory. The types of items normally considered include:

- New equipment
- Modifications to existing equipment and facilities
- Installation
- Other non-recurring costs

### 2. OPERATION AND MAINTENANCE COSTS

The Operation and Maintenance (O&M) category considers the personnel, training and equipment needed to support the system over its life cycle. The author applied a commonly used Coast Guard factor to this category which assumes 80 percent of the initial equipment life cycle costs will be O&M related. The following are considered O&M costs:

- Personnel and facilities
- Training (operators and maintenance technicians)
- Spares inventory
- Repairs

### 3. USAGE FEES

The final cost category to be considered is the usage fees. The usage fees are the estimated line charges assuming the patrol boats will use the system an average of 14 hours per month over the five year life cycle. When viewing the total costs produced by this calculation, consideration must be made of the data rates provided by the satellite

system. In this case, Globalstar promises nearly two times the data rate, for essentially the same usage fee, as AMSC. The author considered the price per data rate when making the pairwise comparison between the alternatives in the cost criterea.

## B. ASSUMPTIONS

The author made the following assumptions based upon common Coast Guard estimating practices. The actual values were obtained from either actual or estimated costs for both equipment and services. The service and equipment costs for Globalstar and Iridium are strictly estimated since service and equipment are not yet available. The results of the calculations based upon the assumptions provided below have been summarized in Table 14.

### 1. ACQUISITION COSTS

- Equipment costs represent about 20% of the total life cycle costs.
- Initial spares are typically equal to 65% to 85% of the equipment purchase price. To be conservative, 85% was used for estimating costs.
- An initial spare parts inventory of 3 sets of spares for every 4 installed units should be adequate.
- Installation will cost about $1000 per cutter for AMSC and $500 per cutter for Iridium and Globalstar.
- There are 85 patrol boats in the Coast Guard.

### 2. OPERATIONAL AND MAINTENANCE COSTS

- Operation and Maintenance costs represent about 80% of the total system life cycle costs.*
- Operation and Maintenance costs are assumed to be linear.
- Five years was used as the system lifetime.

| | AMSC | Iridium | Globalstar |
|---|---|---|---|
| Acquisition Costs<br>Equipment<br>Initial<br>Spares<br>Installation | ($3000/system)<br>$255,000<br>$162,560<br>$85,000 | ($2500/system)<br>$215,500<br>$135,470<br>$42,500 | ($750/system)<br>$63,750<br>$40,640<br>$42,500 |
| Operation and Maintenance (80/20) | $1,020,000 | $850,000 | $255,000 |
| Usage Fees (5yrs)<br>71,400 cutter hours | ($1.50/min)<br>$6,426,000 | ($3.00/min)<br>$12,852,000 | ($1.50/min)<br>$6,426,000 |
| Total Cost: | $7,948,560 | $14,095,470 | $6,827,890 |

Table 14. Life cycle costs for near-term alternatives.

## LIST OF REFERENCES


1. Abrishamkar, Farrokh and Siveski, Zoran. "PCS Global Mobile Satellites." IEEE Communications Magazine Sep. 1996.

2. United States. Coast Guard. Data/Communications System Tactical Operational Requirements. Comdt (G-OLE-1). 1 Apr. 1993.

3. KVH Active Stabilized Antenna Pedestal (ASAP) brochure.

4. United States. Coast Guard. Draft Operations Systems Center Communications Working Group Report. Operations Systems Center. Feb 97.

5. United States. Coast Guard. Law Enforcement Information System II Post-Fielding Natural Working Group Brief. Operations Systems Center. Nov. 96.

6. United States. Coast Guard. LEIS II User Manual. COMDINST M1700.3B. 17 Feb. 1995.

7. Schimelpfenig, Larry. Briefing paper on Shipnet Plus. Dec. 96.

8. United States. Coast Guard. U.S. Coast Guard Information Security Technology Assessment. 25 Aug. 1996.

9. United States. Coast Guard. Communications Technology and Inter-Agency Interoperability Assessment. 07 Aug. 1996.

10. Chong, LT Leda. Demand Assigned Multiple Access (DAMA) Military Satellite Communications (MILSATCOM) for 110' Cutters (Island Class). Draft Report. Mar. 1997.

11. United States. Coast Guard. Commercial Communication Satellite Upgrade/FY99 AC&I (99-300). Draft Resource Change Proposal (RCP). 24 Mar. 1997.

12. Globalstar Backgrounder. White Paper. General Partner, Globalstar L.P. 3 Jan 1997.

13. Motorola LST-5D Product Catalog. 1995.

14. United States. Coast Guard. U.S. Coast Guard Telecommunications Plan - Draft. Commandant (G-SCT). GSA Contract GS11K94BJD0001. 25 Mar. 1995.

15. Balduino, Paulo. "Latin America Goes Wireless via Satellite." IEEE Communications Magazine. Sep. 1995.

16. Seidman, Lawrence P. "Satellites for Wideband Access." IEEE Communications Magazine. Oct. 1996.

17. Cook, William J. "1997 A New Space Odyssey." U.S. News & World Report. 3 Mar. 1997.

18. Tiernan, Frank. "Third Generation Mobile Satellite Communications." Electronic Engineering. 1 Oct. 1996.

19. Skycell Satellite Telephone Rates. (8/96) SKU # 63998. Effective 1 Sep. 1996.

20. "Wavetalk Consumer Specifics." Skysite Satellite Communications. "http://www.skysite.com/products/wavetalk.spec.html"

21. Blodgett, Mindy. "Delayed Satellite Launch Hampers Global Network." PC Magazine. 14 Feb 1997.

22. An Introduction to Military DirecPC. White Paper. Hughes Defense System Theater Defense System. 25 Aug. 1996.

23. Hughes HSSR 2200 Radar System. Product Brochure.

24. Raines, Richard A. and Davis, Nathaniel J. "Personal Communications via Low Earth Orbit Satellite Communication Networks" IEEE Proceedings/MILCOM 1995 V.3. Nov 1995.

25. Horne, William D. and Taylor, Robert M. "New Waves for New Systems". IEEE Spectrum. Oct. 1995.

26. Dondl, Peter. "Standardization of the Satellite Component of the UMTS." IEEE Personal Communications. Oct. 1995.

27. Cox, Donald C. "Wireless Personal Communications: What Is It?" IEEE Personal Communications. Apr. 1995.

28. "Iridium System Overview." "http://www.iridium.com/"

29. Comparetto, Gary and Ramirez, Rafols. "Trends in Mobile Satellite Technology" Computer. Feb. 1997.
"http://www.computer.org/pubs/computer/1997/r2044.htm"

30 "Hundreds of Times Faster."
"http://www.hcisat.com/SPACEWAY/specifications.html"

31. "GALAXY/SPACEWAY." Vectors. Number One, 1996.
"http://www.hughes.com/vectors_96/vectors_01_96/galaxy/
vectors_1_galaxy_spcwy.html"

32. "Teledesic weighs scaled back design." Yahoo Finance. 19 Feb. 1997.
"http://biz.yahoo.com/finance/97/02/19/msft_1.html"

33. "Tor E. Wisloff's Overview of Big LEOs."
"http://www.idt.unit.no/~torwi/overview.htm"

34. Maney, Kevin. "Teledesic, the Internet in the sky, takes shape" Florida Today. 2 Jan. 1997.

35. United States. Coast Guard. Coast Guard Standard Workstation Replacement Project (SWRP) Migration Management Plan. COMDT (G-CPA) 5230. 9 Jun. 1995.

36. Buddenberg, Rex. IS4502 Online Textbook "http://web.nps.navy.mil/~budden/book/two.avail_.html"

37. "The Web, via Thin Air." PC Magazine. Ziff-Dafis publisher. 22 Apr. 1997.

38. Saaty, Thomas L. The Analytic Hierarchy Process. McGraw-Hill Inc. 1980.

39. Bhargava, Hemant, K. "IS-4185, Decision Support Systems Lecture Notes." 1996.

40. Zahed, Fatemeh. "The Analytic Hierarchy Process: A Survey of the Method and its Applications." Interfaces. 16(4): 96-108, July-August 1986.

41 Willis, David. "ENTRUST: Security You Can Manage, Security People Will Use." Network Computing: 50-58, 1 Nov. 1996.

42. "'Net in the sky' gets $9 billion launching", San Jose Mercury News, 30 Apr. 1997, Section C.

43. United States. Joint Chief of Staff. Doctrine for Command, Control, Communications, and Computer (C4) Systems Support to Joint Operations. Joint Pub 6-0, 30 May 1995.

## INITIAL DISTRIBUTION LIST

No. Copies

1. Defense Technical Information Center .......................................... 2
   8725 John J. Kingman Rd., STE 0944
   Ft. Belvoir, VA 22060-6218

2. Dudley Knox Library .......................................................................... 2
   Naval Postgraduate School
   411 Dyer Rd.
   Monterey, CA 93943-5101

3. Professor Suresh Sridhar ..................................................................... 1
   Code SM/SS
   Naval Postgraduate School
   Monterey, CA 93943-5101

4. Professor Rex Buddenberg ................................................................... 1
   Code SM/BU
   Naval Postgraduate School
   Monterey, CA 93943-5101

5. Commandant (G-SCT) ......................................................................... 1
   2100 2nd Street, S.W.
   Washington, D.C. 20593-0001
   Attn: LT Eugene Vogt

6. Commandant (G-SRF) ......................................................................... 1
   2100 2nd Street, S.W.
   Washington, D.C. 20593-0001
   Attn: LCDR Scott Reynolds

7. Commanding Officer.................................................................. 1
Telecommunications & Information
Systems Command
7323 Telegraph Road
Alexandria, VA 22310-3999
Attn: Mr. Larry Schimelpfenig

8. Commanding Officer.................................................................. 1
U.S. Coast Guard
Operations Systems Center
175 Murall Drive
Martinsburg, WV 25401-0200
Attn: Mr Gordon Shillito